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PREFACE

This module is one of a set developed for the Western Alliance for Quality Transportation Construction (WAQTC). WAQTC is an alliance supported by the western state Transportation Departments, along with the Federal Highway Administration (FHWA) and the Western Federal Lands Highway Division (WFLHD) of FHWA. WAQTC's charter includes the following mission.

MISSION

Provide continuously improving quality in transportation construction.

Through our partnership, we will:

- Promote an atmosphere of trust, cooperation, and communication between government agencies and with the private sector.
- Assure personnel are qualified.
- Respond to the requirements of identified needs and new technologies that impact the products that we provide.

BACKGROUND

There are two significant driving forces behind the development of the WAQTC qualification program. One, there is a trend to the use of quality control/quality assurance (QC/QA) specifications. QC/QA specifications include qualification requirements for a contractor's QC personnel and will be requiring WAQTC qualified technicians. Two, Federal regulation on materials sampling and testing (23 CFR 637, *Quality Assurance Procedures for Construction*, published in June 1995) mandates that by June 29, 2000 all testing technicians whose results are used as part of the acceptance decision shall be qualified. In addition, the regulation allows the use of contractor test results to be used as part of the acceptance decision.

OBJECTIVES

WAQTC's objectives for its Transportation Technician Qualification Program include the following:

- To provide highly skilled, knowledgeable materials sampling and testing technicians.
- To promote uniformity and consistency in testing.
- To provide reciprocity for qualified testing technicians between states.
- To create a harmonious working atmosphere between public and private employees based upon trust, open communication, and equality of qualifications.

Training and qualification of transportation technicians is required for several reasons. It will increase the knowledge of laboratory, production, and field technicians — both industry and agency personnel — and increase the number of available, qualified testers. It will reduce problems associated with test result differences. Regional qualification eliminates the issue of reciprocity between states and allows qualified QC technicians to cross state lines without having the concern or need to be requalified by a different program.

The WAQTC Steering Committee

FORWARD

This module is one of five developed for the Western Alliance for Quality Transportation Construction (WAQTC) by AGRA Earth & Environmental, Inc. (AEE). These modules were developed to satisfy the training requirements prescribed by WAQTC for technicians involved in transportation projects. The five modules cover the areas of:

- Aggregate
- Concrete
- Asphalt
- Embankment and Base
- In-place Density

The modules are based upon AASHTO test methods along with procedures developed by WAQTC. They are narrative in style, illustrated, and include step-by-step instruction. There are review questions at the end of each test procedure, which are intended to reinforce the participants' understanding and help participants prepare for the final written and performance exams. Performance exam check lists are also included. The appendices include the corresponding AASHTO and WAQTC test methods.

Each module is in loose-leaf form. This allows updated and state-specific information to be added, as necessary. It will be the technician's responsibility to stay current as changes are made to this living document.

The comments and suggestions of every participant are essential to the continued success and high standards of the Transportation Technician Qualification Program. Please take the time to fill out the Course Evaluation Form as the course progresses and hand it in on the last day of class. If you need additional room to fully convey your thoughts, please use the back of the form.

The WAQTC Steering Committee

GUIDANCE FOR COURSE EVALUATION FORM

The Course Evaluation Form on the following page is very important to the continuing improvement and success of this course. The form is included in each Participant Workbook. During the course introduction, the Instructor will call the participants' attention to the form, its content, and the importance of its thoughtful completion at the end of the course. Participants will be encouraged to keep notes, or write down comments as the class progresses, in order to provide the best possible evaluation. The Instructor will direct participants to write down comments at the end of each day and to make use of the back of the form if more room is needed for comments.

On the last day of the course, just prior to the written examination, the Instructor will again refer to the form and instruct participants that completion of the form after their last examination is a requirement prior to leaving. Should the course have more than one Instructor, participants should be directed to list them as A, B, etc., with the Instructor's name beside the letter, and direct their answers in the Instructor Evaluation portion of the form accordingly.

WESTERN ALLIANCE FOR QUALITY TRANSPORTATION CONSTRUCTION COURSE EVALUATION FORM

The WAQTC Transportation Technician Qualification Program would appreciate your thoughtful completion of all items on this evaluation form. Your comments and constructive suggestions will be an asset in our continuing efforts to improve our course content and presentations.

Course Title: ______________________________

Location: ______________________________

Dates: ______________________________

Your Name (Optional): ______________________________

Employer: ______________________________

Instructor(s) ______________________________

COURSE CONTENT

Will the course help you perform your job better and with more understanding? Yes Maybe No

Explain: ______________________________

____

Was there an adequate balance between theory, instruction, and hands-on application? Yes Maybe No

Explain: ______________________________

____

Did the course prepare you to confidently complete both examinations? Yes Maybe No

Explain: ______________________________

____

What was the most beneficial aspect of the course? ______________________________

____

What was the least beneficial aspect of the course? ______________________________

____

GENERAL COMMENTS

General comments on the course, content, materials, presentation method, facility, registration process, etc. Include suggestions for additional Tips!

INSTRUCTOR EVALUATION

Were the objectives of the course, and the instructional and exam approach, clearly explained? Yes Maybe No

Explain:

Was the information presented in a clear, understandable manner? Yes Maybe No

Explain:

Did the instructors demonstrate a good knowledge of the subject? Yes Maybe No

Explain:

Did the instructors create an atmosphere in which to ask questions and hold open discussion? Yes Maybe No

Explain:

COURSE OBJECTIVES AND SCHEDULE (EMBANKMENT AND BASE)

Learning Objectives

Instructional objectives for this course include:

- Being familiar with Quality Assurance (QA) concepts
- Developing a background in measurements and calculations
- Being knowledgeable in highway materials terminology
- Respecting safety issues
- Acquiring knowledge of random sampling techniques
- Understanding the basics of compaction and density control
- Becoming proficient in the following quality control test procedures:

  FOP for AASHTO T 255
  Total Moisture Evaporable Content of Aggregate by Drying; and
  AASHTO T 265
  Laboratory Determination of Moisture Content of Soils

  FOP for AASHTO T 217
  Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester

  FOP for AASHTO T 99
  Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop;
  AASHTO T 180
  Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop

  FOP for AASHTO T 272
  Family of Curves -- One-Point Method

  FOP for FOP for AASHTO T 85
  Specific Gravity and Absorption of Coarse Aggregate

  FOP for AASHTO T 224
  Correction for Coarse Particles in the Soil Compaction Test

  FOP for AASHTO T 89
  Determining the Liquid Limit of Soils

  FOP for AASHTO T 90
  Determining the Plastic Limit and Plasticity Index of Soils

The overall goals of this embankment and base course are to understand compaction and density control and to be competent with specific quality control test procedures identified for the Transportation Technician Qualification Program of the Western Alliance for Quality Transportation Construction (WAQTC). Additional studies beyond this course will be required for those desiring greater in-depth knowledge of the theory behind the test procedures included herein.

Course Outline and Suggested Schedule

Day One

0800	Welcome Introduction of Instructors Introduction and Expectations of Participants
0815	WAQTC Mission and TTQP Objectives Instructional Objectives for the Course Overview of the Course Course Evaluation Form
0830	Review of Quality Assurance Concepts
0845	Background in Measurements and Calculations
0945	Break
1000	Random Sampling
1030	Basics of Compaction and Density Control
1045	Total Evaporable Moisture Content of Aggregate by Drying FOP for AASHTO T 255 Laboratory Determination of Moisture Content of Soils FOP for AASHTO T 265
1115	Determination of Moisture in Soils by Means of Calcium Chloride Gas Pressure Moisture Tester FOP for AASHTO T 217
1130	Review Questions Questions and Answers
1200	Lunch

1315	Moisture-Density Relations of Soils: Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop FOP for AASHTO T 99 Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in.) Drop FOP for AASHTO T 180
1400	Laboratory Practice Moisture Content and Moisture-Density Relations
1645	Evaluation End of Day

Day Two

0800	Questions from the Previous Day
0815	Family of Curves -- One-Point Method FOP for AASHTO T 272
0830	Laboratory Practice Moisture Content and Moisture-Density Relations (continued)
0945	Break
1000	Specific Gravity and Absorption of Coarse Aggregate FOP for AASHTO T 85
1030	Laboratory Practice Specific Gravity and Absorption
1130	Review Questions Questions and Answers
1200	Lunch
1315	Laboratory Practice Moisture Content and Moisture-Density Relations (continued) Specific Gravity and Absorption (continued)
1645	Evaluation End of Day

Day Three

0800	Questions from Previous Day
0815	Correction for Coarse Particles in the Soil Compaction Test FOP for AASHTO T 224
0845	Determining the Liquid Limit of Soils FOP for AASHTO T 89
0900	Determining the Plastic Limit and Plasticity Index of Soils FOP for AASHTO T 90
0915	Review Questions Questions and Answers
0945	Break
1000	Laboratory Demonstration Liquid Limit and Plastic Limit
1200	Lunch
1315	Laboratory Practice Completion of any Moisture Content Determinations
1645	Evaluation End of day

Day Four

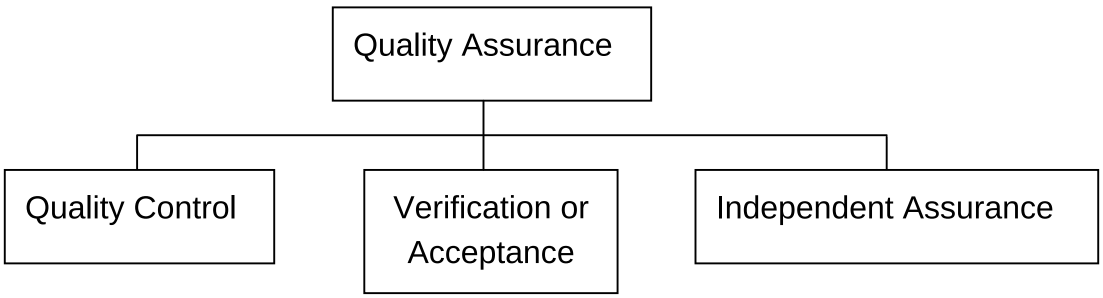
0800	Questions from Previous Day
0815	Instruction on Use of AKDOT&PF ATM-12, ITD T-74, WSDOT TM 606, or WFLHD Humphreys Curves
1000	Start of Exams
	Participants will break into groups so that written and practical exams may be given concurrently.
	Evaluation

QUALITY ASSURANCE CONCEPTS

The Federal Highway Administration (FHWA) has established requirements that each 01
State Highway Agency (SHA) must develop a Quality Assurance (QA) Program that is
approved by the FHWA for projects on the National Highway System (NHS). In
addition to complying with this requirement, implementing QA specifications in a 02
construction program includes the benefit of improvement of overall quality of highway
and bridge construction.

A QA Program may include three separate and distinct parts as illustrated below.

03



Quality Assurance (QA) are those planned and systematic actions necessary to provide 04
confidence that a product or service will satisfy given requirements for quality.

Quality Control (QC) are those operational, process control techniques or activities that 05
are performed or conducted to fulfill contract requirements for material and equipment quality. In some states, the constructor is responsible for providing QC sampling and testing, while in other states the SHA handles QC. Where the constructor is responsible for QC tests, the results may be used for acceptance only if verified or accepted by additional tests performed by an independent group.

Verification/Acceptance consists of the sampling and testing performed to validate QC 06
sampling and testing and, thus, the quality of the product. Verification/Acceptance samples are obtained and tests are performed independently from those involved with QC. Samples taken for QC tests may not be used for Verification/Acceptance testing.

Independent Assurance (IA) are those activities that are an unbiased and independent 07
evaluation of all the sampling and testing procedures used in QC and Verification/Acceptance. IA may use a combination of laboratory certification, technician qualification or certification, proficiency samples, and/or split samples to assure that QC and Verification/Acceptance activities are valid. Agencies may qualify or certify laboratories and technicians, depending on the state in which the work is done.

BACKGROUND ON MEASUREMENTS AND CALCULATIONS

01 Introduction

This section provides a background in the mathematical rules and procedures used in making measurements and performing calculations. Topics include:

- Units: Metric vs. English
- Mass vs. Weight
- Balances and Scales
- Rounding
- Significant Figures
- Accuracy and Precision
- Tolerance

Also included is discussion of real-world applications in which the mathematical rules and procedures may not be followed.

02 Units: Metric vs. English

Basic units in SI include:

Length:	meter, m
Mass:	kilogram, kg
Time:	second, s

Derived units in SI include:

Force:	Newton, N

SI units

03 The bulk of this document uses dual units. Metric units are followed by Imperial, more commonly known as English, units in parentheses. For example: 25 mm (1 in.). Exams are presented in metric or English.

04 Depending on the situation, some conversions are exact, and some are approximate. One inch is exactly 25.4 mm. If a procedure calls for measuring to the closest 1/4 in., however, 5 mm is close enough. We do not have to say 6.35 mm. That is because 1/4 in. is half way between 1/8 in. and 3/8 in. – or half way between 3.2 and 9.5 mm. Additionally, the tape measure or rule used may have 5 mm marks, but may not have 1 mm marks and certainly will not be graduated in 6 mm increments.

Metric	English
25 mm	1 in.
1 kg	2.2 lb
1000 kg/m^3	62.4 lb/ft^3
25 MPa	3600 lb/in.^{2}

Some approximate conversions

In SI (Le Systeme International d’Unites), the basic unit of mass is the kilogram (kg) and the basic unit of force, which includes weight, is the Newton (N). Mass in this document is given in grams (g) or kg. See the section below on “Mass vs. Weight” for further discussion of this topic.

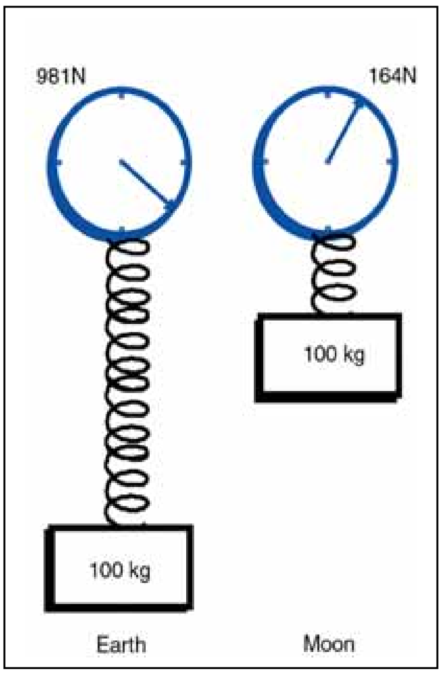
Mass vs. Weight

05 The terms mass, force, and weight are often confused. Mass, m, is a measure of an object's material makeup, and has no direction. Force, F, is a measure of a push or pull, and has the direction of the push or pull. Force is equal to mass times acceleration, a.

06

$$F = ma$$

Weight, W, is a special kind of force, caused by gravitational acceleration. It is the force required to suspend or lift a mass against gravity. Weight is equal to mass times the acceleration due to gravity, g, and is directed toward the center of the earth.



Comparison of mass and weight

$$W = mg$$

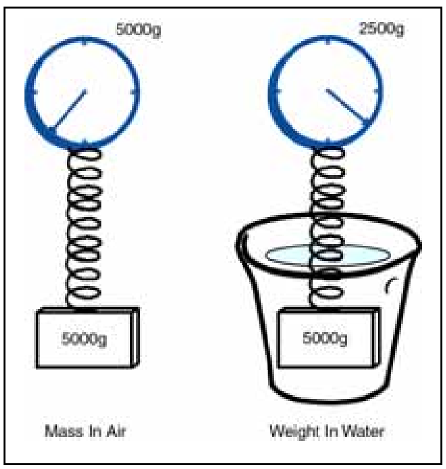
In SI, the basic unit of mass is the kilogram (kg), the units of acceleration are meters per square second (m/s^2), and the unit of force is the Newton (N). Thus a person having a mass of 84 kg subject to the standard acceleration due to gravity, on earth, of 9.81 m/s^2 would have a weight of:

$$W = (84.0 \text{ kg})(9.81 \text{ m/s}^2) = 824 \text{ kg-m/s}^2 = 824 \text{ N}$$

07 In the English system, mass can be measured in
pounds-mass (lb_m), while acceleration is in feet per
08 square second (ft/s^2), and force is in pounds-force (lb_f). A person weighing 185 lb_f on a scale has a mass of 185 lb_m when subjected to the earth's standard gravitational pull. If this person were to go to the moon, where the acceleration due to gravity is about one-sixth of what it is on earth, the person's weight would be about 31 lb_f, while his or her mass would remain 185 lb_m. Mass does not depend on location, but weight does.

While the acceleration due to gravity does vary with position on the earth (latitude and elevation), the variation is not significant except for extremely precise work – the manufacture of electronic memory chips, for example.

As discussed above, there are two kinds of pounds, lb_m and lb_f. In laboratory measurements of mass, the gram or kilogram is the unit of choice. But, is
09 this mass or force? Technically, it depends on the instrument used, but practically speaking, mass is the result of the measurement. When using a scale, force is being measured – either electronically by the stretching of strain gauges or mechanically by the stretching of a spring or other device. When using a balance, mass is being measured, because the mass of the object is being compared to a known mass built into the balance.



Submerged weight

In this document, mass, not weight, is used in test procedures except when determining “weight” in water. When an object is submerged in water (as is done in specific gravity tests), the term weight is used. Technically, what is being measured is the force the object exerts on the balance or scale while the object is submerged in water (or the submerged weight). This force is actually the weight of the object less the weight of the volume of water displaced.

In summary, whenever the common terms “weight”
10 and “weighing” are used, the more appropriate
11 terms “mass” and “determining mass” are usually implied, except in the case of weighing an object submerged in water.

12

Balances and Scales

Balances, technically used for mass determinations, and scales, used to weigh items, were discussed briefly above in the section on “Mass vs. Weight.” In field operating procedures, we usually do not differentiate between the two types of instruments. When using either one for a material or object in air, we are determining <u>mass</u>. For those procedures in which the material or object is suspended in water, we are determining <u>weight</u> in water.

13 AASHTO recognizes two general categories of
instruments. Standard analytical balances are used
in laboratories. For most field operations, general
purpose balances and scales are specified.
Specifications for both categories are shown in
14 Tables 1 and 2.

Table 1
Standard Analytical Balances

Class	Capacity	Readability and Sensitivity	Accuracy
A	200 g	0.0001 g	0.002 g
B	200 g	0.001 g	0.002 g
C	1200 g	0.01 g	0.02 g

Table 2
General Purpose Balances and Scales

Class	Principal Sample Mass	Readability and Sensitivity	Accuracy
G2	2 kg or less	0.1 g	0.1 g or 0.1 percent
G5	2 kg to 5 kg	1 g	1 g or 0.1 percent
G20	5 kg to 20 kg	5 g	5 g or 0.1 percent
G100	Over 20 kg	20 g	20 g or 0.1 percent

15 Rounding

Numbers are commonly rounded up or down after measurement or calculation. For example, 53.67 would be rounded to 53.7 and 53.43 would be rounded to 53.4, if rounding were required. The first number was rounded up because 53.67 is closer to 53.7 than to 53.6. Likewise, the second number was rounded down because 53.43 is closer to 53.4 than to 53.5. The reasons for rounding are covered in the next section on “Significant Figures.”

If the number being rounded ends with a 5, two possibilities exist. In the more mathematically sound approach, numbers are rounded up or down depending on whether the number to the left of the 5 is odd or even. Thus, 102.25 would be rounded down to 102.2, while 102.35 would be rounded up to 102.4. This procedure avoids the bias that would exist if all numbers ending in 5 were rounded up or all numbers were rounded down. In some calculators, however, all rounding is up. This does result in some bias, or skewing of data, but the significance of the bias may or may not be significant to the calculations at hand.

Significant Figures

- General

16 A general purpose balance or scale, classified as G20 in AASHTO M 231, has a capacity of 20,000 g and an accuracy requirement of ±5 g. A mass of 18,285 g determined with such an instrument could actually range from 18,280 g to 18,290 g. Only <u>four</u> places in the measurement are significant. The fifth (last) place is <u>not</u> significant since it may change.

17 Mathematical rules exist for handling significant figures in different situations.
An example in Metric(**m**) or English(**ft**), when performing addition and subtraction, the number of significant figures in the sum or difference is determined by the least precise input. Consider the three situations shown below:

<u>Situation 1</u>	<u>Situation 2</u>	<u>Situation 3</u>
35.67	143.903	162
+ 423.938	- 23.6	+33.546
		- .022
= 459.61	= 120.3	= 196
not 459.608	not 120.303	not 195.524

Rules also exist for multiplication and division. These rules, and the rules for mixed operations involving addition, subtraction, multiplication, and/or division, are beyond the scope of these materials. AASHTO covers this topic to a certain extent in the section called “Precision” or “Precision and Bias” included in many test methods, and the reader is directed to those sections if more detail is desired.

18 • Real World Limitations

While the mathematical rules of significant digits have been established, they are not always followed. For example, AASHTO Method of Test T 176, *Plastic Fines in Graded Aggregates and Soils by the Use of the Sand Equivalent Test*, prescribes a method for rounding and significant digits in conflict with the mathematical rules.

In this procedure, readings and calculated values are always rounded up. A clay reading of 7.94 would be rounded to 8.0 and a sand reading of 3.21 would be rounded to 3.3. The <u>rounded</u> numbers are then used to calculate the Sand Equivalent, which is the ratio of the two numbers multiplied by 100. In this case:

$$\frac{3.3}{8.0} \times 100 = 41.250...,$$

rounded to 41.3 and reported as 42

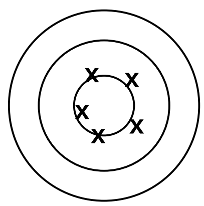
$$(\text{Not}: \frac{3.21}{7.94} \times 100 = 40.428...,$$

rounded to 40.0 and reported as 40)

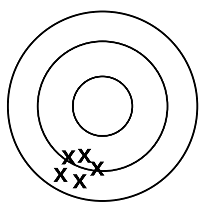
It is extremely important that engineers and technicians understand the rules of rounding and significant digits just as well as they know procedures called for in standard test methods.

Accuracy and Precision

19 Although often used interchangeably, the terms accuracy and precision do not mean the same thing. In an engineering sense, accuracy denotes nearness to the truth or some value accepted as the truth,
20 while precision relates to the degree of refinement or repeatability of a measurement.



ACCURATE BUT NOT PRECISE, SCATTERED



PRECISE BUT NOT ACCURATE, BIASED

Two bullseye targets are shown to the left. The upper one indicates hits that are scattered and, yet, are very close to the center. The lower one has a tight pattern, but all the shots are biased from the center. The upper one is more accurate, while the lower one is more precise. A biased, but precise, instrument can often be adjusted physically or mathematically to provide reliable single measurements. A scattered, but accurate, instrument can be used if enough measurements are made to provide a valid average.

Consider the measurement of the temperature of boiling water at standard atmospheric pressure by
21 two thermometers. Five readings were taken with each, and the values were averaged.

Thermometer No. 1		Thermometer No. 2	
101.2°	214.2°	100.6°	213.1°
101.1°	214.0°	99.2°	210.6°
101.2°	214.2°	98.9°	210.0°
101.1°	214.0°	101.0°	213.8°
101.2°	214.2°	100.3°	212.5°
AVG = 101.2°	214.2°	AVG = 100.0°	212°

No. 1 shows very little fluctuation, but is off the
22 known boiling point (100°C or 212°F) by 1.2°C or 2.2°F. No. 2 has an average value equal to the known boiling point, but shows quite a bit of fluctuation. While it might be preferable to use neither thermometer, thermometer No. 1 could be

employed if 1.2°C or 2.2°F were subtracted from each measurement. Thermometer No. 2 could be
23 used if enough measurements were made to provide a valid average.

24 Engineering and scientific instruments should be calibrated and compared against reference standards periodically to assure that measurements are accurate. If such checks are not performed, the accuracy is uncertain, no matter what the precision. Calibration of an instrument removes fixed error,
25 leaving only random error for concern.

Tolerance

Dimensions of constructed or manufactured objects,
26 including laboratory test equipment, cannot be specified exactly. Some tolerance must be allowed. Thus, procedures for including tolerance in addition/subtraction and multiplication/division operations must be understood.

- Addition and Subtraction

27

  When adding or subtracting two numbers that individually have a tolerance, the tolerance of the sum or difference is equal to the sum of the individual tolerances.

  An example in Metric(**m**) or English(**ft**), if the distance between two points is made up of two parts, one being 113.361 ±0.006 and the other being 87.242 ±0.005 then the tolerance of the sum (or the difference) is:

  (0.006) + (0.005) = 0.011

  and the sum would be 200.603 ±0.011.

- Multiplication and Division

28 To demonstrate the determination of tolerance again in either Metric(**m**) or English(**ft**) for the product of two numbers, consider determining the area of a rectangle having sides of 76.254

±0.009 and 34.972 ±0.007. The percentage variations of the two dimensions are:

$$\frac{0.009}{76.254} \times 100 = 0.01\% \qquad \frac{0.007}{34.972} \times 100 = 0.02\%$$

The sum of the percentage variations is 0.03 percent – the variation that is employed in the area of the rectangle:

Area =
2666.8 (m^2 or ft^2) ±0.03 percent = 2666.8 ± 0.8 (m^2 or ft^2).

- Real World Applications

29 Tolerances are used whenever a product is manufactured. For example, the mold used for determining soil density in AASHTO T 99 has a diameter of 101.60 ±0.41 mm(4.000 ±0.016 in) and a height of 116.43 ±0.13 mm(4.584 ±0.005 in).

Using the smaller of each dimension results in a volume of:

$(\pi/4)$ (101.19 mm)^2 (116.30 mm) =
935,287 mm^3 or 0.000935 m^3

$(\pi/4)$ (3.984 in)^2 (4.579 in) =
57.082in^3 or 0.0330 ft^3

Using the larger of each dimension results in a volume of:

$(\pi/4)$ (102.01 mm)^2 (116.56 mm) =
952,631 mm^3 or 0.000953 m^3

$(\pi/4)$ (4.016 in)^2 (4.589 in) =
58.130 in^3 or 0.0336 ft^3

The average value is 0.000944 m^3 (0.0333), and AASHTO T 99 specifies a volume of:

0.000943 ±0.000008 m^3
or a range of
0.000935 to 0.000951 m^3

0.0333 ±0.0003 ft^3
or a range of
0.0330 to 0.0336 ft^3

Because of the variation that can occur, some agencies periodically calibrate molds, and make adjustments to calculated density based on those calculations.

Summary

Mathematics has certain rules and procedures for making measurements and performing calculations that are well established. So are standardized test procedures. Sometimes these agree, but occasionally, they do not. Engineers and technicians must be familiar with both, but must follow test procedures in order to obtain valid, comparable results.

TERMINOLOGY

Many of the terms listed below are defined differently by various agencies or organizations. The definitions of the American Association of State Highway and Transportation Officials (AASHTO) are the ones most commonly used in this document.

Absorbed water – Water drawn into a solid by absorption, and having physical properties similar to ordinary water.

Absorption – The increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass.

ACC batch plant – A manufacturing facility for producing asphalt cement concrete (ACC) that proportions aggregate by weight and asphalt by weight or volume.

ACC continuous mix plant – A manufacturing facility for producing asphalt cement concrete (ACC) that proportions aggregate and asphalt by a continuous volumetric proportioning system without specific batch intervals.

Acceptance – See verification.

Acceptance program – All factors that comprise the State Highway Agency's (SHA) determination of the quality of the product as specified in the contract requirements. These factors include verification sampling, testing, and inspection and may include results of quality control sampling and testing.

Admixture – Material other than water, cement, and aggregates in portland cement concrete (PCC).

Adsorbed water – Water attached to the surface of a solid by electrochemical forces, and having physical properties substantially different from ordinary water.

Aggregate – Hard granular material of mineral composition, including sand, gravel, slag or crushed stone, used in roadway base and in portland cement concrete (PCC) and asphalt cement concrete (ACC).

- **Coarse aggregate –** Aggregate retained on or above the 4.75 mm (No. 4) sieve.
- **Coarse-graded aggregate –** Aggregate having a predominance of coarse sizes.
- **Dense-graded aggregate –** Aggregate having a particle size distribution such that voids occupy a relatively small percentage of the total volume.
- **Fine aggregate –** Aggregate passing the 4.75 mm (No. 4) sieve.
- **Fine-graded aggregate** – Aggregate having a predominance of fine sizes.
- **Mineral filler –** A fine mineral product at least 70 percent of which passes a 75 µm (No. 200) sieve.

- **Open-graded gap-graded aggregate –** Aggregate having a particle size distribution such that voids occupy a relatively large percentage of the total volume.
- **Well-Graded Aggregate –** Aggregate having an even distribution of particle sizes.

Aggregate storage bins – Bins that store aggregate for feeding material to the dryer in a hot mix asphalt (HMA) plant in substantially the same proportion as required in the finished mix.

Agitation – Provision of gentle motion in portland cement concrete (PCC) sufficient to prevent segregation and loss of plasticity.

Air voids – Total volume of the small air pockets between coated aggregate particles in asphalt cement concrete (ACC); expressed as a percentage of the bulk volume of the compacted paving mixture.

Ambient temperature – Temperature of the surrounding air.

Angular aggregate – Aggregate possessing well-defined edges at the intersection of roughly planar faces.

Apparent specific gravity – The ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of water.

Asphalt – A dark brown to black cementitious material in which the predominate constituents are bitumens occurring in nature or obtained through petroleum processing. Asphalt is a constituent of most crude petroleums.

Asphalt cement – An asphalt specially prepared in quality and consistency for use in the manufacture of asphalt cement concrete (ACC).

Asphalt cement concrete (ACC) – A controlled mix of aggregate and asphalt cement.

Automatic cycling control – A control system in which the opening and closing of the weigh hopper discharge gate, the bituminous discharge valve, and the pugmill discharge gate are actuated by means of automatic mechanical or electronic devices without manual control. The system includes preset timing of dry and wet mixing cycles.

Automatic dryer control – A control system that automatically maintains the temperature of aggregates discharged from the dryer.

Automatic proportioning control – A control system in which proportions of the aggregate and asphalt fractions are controlled by means of gates or valves that are opened and closed by means of automatic mechanical or electronic devices without manual control.

Bag (of cement) – 94 lb of portland cement. (Approximately 1 ft^3 of bulk cement.)

Base – A layer of selected material constructed on top of subgrade or subbase and below the paving on a roadway.

Bias – The offset or skewing of data or information away from its true or accurate position as the result of systematic error.

Binder – Asphalt cement or modified asphalt cement that binds the aggregate particles into a dense mass.

Boulders – Rock fragment, often rounded, with an average dimension larger than 300 mm (12 in.).

Bulk specific gravity – The ratio of the mass, in air, of a volume of aggregate or compacted HMA mix (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of water.

Bulk specific gravity (SSD) – The ratio of the mass, in air, of a volume of aggregate or compacted HMA mix, including the mass of water within the voids (but not including the voids between particles), to the mass of an equal volume of water. (See saturated surface dry.)

Cementitious Materials – cement and pozzolans used in concrete such as; Portland Cement, fly ash, silica fume, & blast-furnace slag.

Clay – Fine-grained soil that exhibits plasticity over a range of water contents, and that exhibits considerable strength when dry. Also, that portion of the soil finer than 2 µm.

Cobble – Rock fragment, often rounded, with an average dimension between 75 and 300 mm (3 and 12 in.).

Cohesionless soil – Soil with little or no strength when dry and unconfined or when submerged, such as sand.

Cohesive soil – Soil with considerable strength when dry and that has significant cohesion when unconfined or submerged.

Compaction – Densification of a soil or hot mix asphalt (HMA) by mechanical means.

Compaction curve (Proctor curve or moisture-density curve) – The curve showing the relationship between the dry unit weight or density and the water content of a soil for a given compactive effort.

Compaction test (moisture-density test) – Laboratory compaction procedure in which a soil of known water content is placed in a specified manner into a mold of given dimensions, subjected to a compactive effort of controlled magnitude, and the resulting density determined.

Compressibility – Property of a soil or rock relating to susceptibility to decrease in volume when subject to load.

Constructor – The builder of a project. The individual or entity responsible for performing and completing the construction of a project required by the contract documents. Often called a contractor, since this individual or entity contracts with the owner.

Crusher-run – The total unscreened product of a stone crusher.

Delivery tolerances – Permissible variations from the desired proportions of aggregate and asphalt cement delivered to the pugmill.

Density – The ratio of mass to volume of a substance. Usually expressed in kg/m^3.

Design professional – The designer of a project. This individual or entity may provide services relating to the planning, design, and construction of a project, possibly including materials testing and construction inspection. Sometimes called a "contractor", since this individual or entity contracts with the owner.

Dryer – An apparatus that dries aggregate and heats it to specified temperatures.

Dry mix time – The time interval between introduction of aggregate into the pugmill and the addition of asphalt cement.

Durability – The property of concrete that describes its ability to resist disintegration by weathering and traffic. Included under weathering are changes in the pavement and aggregate due to the action of water, including freezing and thawing.

Effective diameter (effective size) – D_{10}, particle diameter corresponding to 10 percent finer or passing.

Embankment – Controlled, compacted material between the subgrade and subbase or base in a roadway.

End-result specifications – Specifications that require the Constructor to take the entire responsibility for supplying a product or an item of construction. The Owner's (the highway agency's) responsibility is to either accept or reject the final product or to apply a price adjustment that is commensurate with the degree of compliance with the specifications. Sometimes called performance specifications, although considered differently in highway work. (See performance specifications.)

Field operating procedure (FOP) – Procedure used in field testing on a construction site or in a field laboratory. (Based on AASHTO or NAQTC test methods.)

Fineness modulus – A factor equal to the sum of the cumulative percentages of aggregate retained on certain sieves divided by 100; the sieves are 150, 75, 37.5, 19.0, 9.5, 4.75, 2.36, 1.18, 0.60, 0.30, and 0.15 mm. Used in the design of concrete mixes. The lower the fineness modulus, the more water/cement paste that is needed to coat the aggregate.

Fines – Portion of a soil or aggregate finer than a 75 µm (No. 200) sieve. Also silts and clays.

Free water – Water on aggregate available for reaction with hydraulic cement. Mathematically, the difference between total moisture content and absorbed moisture content.

Glacial till – Material deposited by glaciation, usually composed of a wide range of particle sizes, which has not been subjected to the sorting action of water.

Gradation (grain-size distribution) – The proportions by mass of a soil or fragmented rock distributed by particle size.

Gradation analysis (grain size analysis or sieve analysis) – The process of determining grain-size distribution by separation of sieves with different size openings.

Hot aggregate storage bins – Bins that store heated and separated aggregate prior to final proportioning into the mixer.

Hot mix asphalt (HMA) – High quality, thoroughly controlled hot mixture of asphalt cement and well-graded, high quality aggregate.

Hydraulic cement – Cement that sets and hardens by chemical reaction with water.

Independent assurance – Unbiased and independent evaluation of all the sampling and testing procedures, equipment, and technicians involved with Quality Control (QC) and Verification/Acceptance.

In situ – Rock or soil in its natural formation or deposit.

Liquid limit – Water content corresponding to the boundary between the liquid and plastic states.

Loam – A mixture of sand, silt and/or clay with organic matter.

Lot – A quantity of material to be controlled. It may represent a specified mass, a specified number of truckloads, or a specified time period during production.

Manual proportioning control – A control system in which proportions of the aggregate and asphalt fractions are controlled by means of gates or valves that are opened and closed by manual means. The system may or may not include power assisted devices in the actuation of gate and valve opening and closing.

Materials and methods specifications – Also called prescriptive specifications. Specifications that direct the Constructor to use specified materials in definite proportions and specific types of equipment and methods to place the material.

Maximum size – One sieve larger than nominal maximum size.

Mesh – The square opening of a sieve.

Moisture content – The ratio, expressed as a percentage, of the mass of water in a material to the dry mass of the material.

Nominal maximum size – One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

> ***Note:*** - The first sieve to normally retain more than 10% of the material usually is the second sieve in the stack but may be the third sieve.

Nuclear gauge – Instruments used to measure in-place density, moisture content, or asphalt content through the measurement of nuclear emissions.

Optimum moisture content (optimum water content) – The water content at which a soil can be compacted to a maximum dry density by a given compactive effort.

Organic soil – Soil with a high organic content.

Owner – The organization that conceives of and eventually operates and maintains a project. A State Highway Agency (SHA) is an Owner.

Paste – Mix of water and hydraulic cement that binds aggregate in portland cement concrete (PCC).

Penetration – The consistency of a bituminous material, expressed as the distance in tenths of a millimeter (0.1 mm) that a standard needle vertically penetrates a sample of the material under specified conditions of loading, time, and temperature.

Percent compaction – The ratio of density of a soil, aggregate, or HMA mix in the field to maximum density determined by a standard compaction test, expressed as a percentage.

Performance specifications – Specifications that describe how the finished product should perform. For highways, performance is typically described in terms of changes over time in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as “failure.” Specifications containing warranty/guarantee clauses are a form of performance specifications.

Plant screens – Screens located between the dryer and hot aggregate storage bins that separate the heated aggregates by size.

Plastic limit – Water content corresponding to the boundary between the plastic and the semisolid states.

Plasticity – Property of a material to continue to deform indefinitely while sustaining a constant stress.

Plasticity index – Numerical difference between the liquid limit and the plastic limit and, thus, the range of water content over which the soil is plastic.

Portland cement – Hydraulic cement produced by pulverizing portland cement clinker.

Portland cement concrete (PCC) – A controlled mix of aggregate, portland cement, and water, and possibly other admixtures.

PCC batch plant – A manufacturing facility for producing portland cement concrete.

Prescriptive specifications – See Materials and Methods specification.

Proficiency samples – Homogeneous samples that are distributed and tested by two or more laboratories. The test results are compared to assure that the laboratories are obtaining the same results.

Pugmill – A shaft mixer designed to mix aggregate and cement.

Quality assurance – Planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality. The overall system for providing quality in a constructed project, including Quality Control (QC), Verification/Acceptance, and Independent Assurance (IA).

Quality assurance specifications – Also called QC/QA specifications. A combination of end-result (performance) specifications and materials and methods (prescriptive) specifications. The Constructor is responsible for quality control, and the Owner (highway agency) is responsible for acceptance of the product.

Quality control (QC) – Operational, process control techniques or activities that are performed or conducted to fulfill contract requirements for material or equipment quality.

Random sampling – Procedure for obtaining non-biased, representative samples.

Sand – Particles of rock passing the 4.75 mm (No. 4) sieve and retained on the 75 µm (No. 200) sieve.

Saturated surface dry (SSD) – Condition of an aggregate particle, asphalt cement concrete (ACC) or portland cement concrete (PCC) core, or other porous solid when the permeable voids are filled with water, but no water is present on exposed surfaces. (See bulk specific gravity.)

Segregation – The separation of aggregate by size resulting in a non-uniform material.

SHRP – The Strategic Highway Research Program (SHRP) established in 1987 as a five-year research program to improve the performance and durability of roads and to make those roads safe for both motorists and highway workers. SHRP research funds were partly used for the development of performance-based specifications to directly relate laboratory analysis with field performance.

Sieve – Laboratory apparatus consisting of wire mesh with square openings, usually in circular or rectangular frames.

Silt – Material passing the 75 µm (No. 200) sieve that is non-plastic or very slightly plastic, and that exhibits little or no strength when dry and unconfined. Also, that portion of the soil finer than 75 µm and coarser than 2 µm.

Slump – Measurement related to the workability of concrete.

Soil – Sediments or unconsolidated accumulations of solid particles produced by the physical and chemical disintegration or rocks, and which may or may not contain organic matter.

Specific gravity – The ratio of the mass, in air, of a volume of a material to the mass of an equal volume of water.

Stability – The ability of an asphalt cement concrete (ACC) to resist deformation from imposed loads. Stability is dependent upon internal friction, cohesion, temperature, and rate of loading.

Stratified random sampling – Procedure for obtaining non-biased, representative samples in which the established lot size is divided into equally-sized sublots.

Subbase – A layer of selected material constructed between the subgrade and the base coarse in a flexible HMA roadway, or between the subgrade and portland cement concrete (PCC) pavement in a rigid PCC roadway.

Subgrade – Natural soil prepared and compacted to support a structure or roadway pavement.

Sublot – A segment of a lot chosen to represent the total lot.

Superpave™ – Superpave™ (Superior Performing Asphalt Pavement) is a trademark of the Strategic Highway Research Program (SHRP). Superpave™ is a product of the SHRP asphalt research. The Superpave™ system incorporates performance-based asphalt materials characterization with design environmental conditions to improve performance by controlling rutting, low temperature cracking and fatigue cracking. The three major components of Superpave™ are the asphalt binder specification, the mix design and analysis system, and a computer software system.

Theoretical maximum specific gravity – The ratio of the mass of a given volume of asphalt cement concrete (ACC) with no air voids to the mass of an equal volume of water, both at a stated temperature.

Topsoil – Surface soil, usually containing organic matter.

Uniformity coefficient – C_u, a value employed to quantify how uniform or well-graded an aggregate is: $C_u = D_{60}/D_{10}$. 60 percent of the aggregate, by mass, has a diameter smaller than D_{60} and 10 percent of the aggregate, by mass, has a diameter smaller than D_{10}.

Unit weight – The ratio of weight to volume of a substance. The term “density” is more commonly used.

µm – Micro millimeter (micron) Used as measurement for sieve size.

Vendor – Supplier of project-produced material that is other than the constructor.

Verification – Process of sampling and testing performed to validate Quality Control (QC) sampling and testing and, thus, the quality of the product. Sometimes called Acceptance.

Viscosity – A measure of the resistance to flow; one method of measuring the consistency of asphalt.

- **Absolute viscosity –** A method of measuring viscosity using the “poise” as the basic measurement unit. This method is used at a temperature of 60°C, typical of hot pavement.

- **Kinematic viscosity –** A method of measuring viscosity using the stoke as the basic measurement unit. This method is used at a temperature of 135°C, typical of hot asphalt at a plant.

Void in the mineral aggregate (VMA) – The volume of inter-granular void space between aggregate particles of compacted asphalt cement concrete (ACC) that includes air and asphalt; expressed as a percentage of the bulk volume of the compacted paving mixture.

Voids filled with asphalt – The portion of the void in the mineral aggregate (VMA) that contains asphalt; expressed as a percentage of the bulk volume of mix or the VMA.

Wet mixing period – The time interval between the beginning of application of asphalt material and the opening of the mixer gate.

Zero air voids curve (saturation curve) – Curve showing the zero air voids density as a function of water content.

SAFETY

The procedures included in this manual may involve hazardous materials, operations, and equipment. The procedures do not address all of the safety issues associated with their use. It is the responsibility of the employer to assess workplace hazards and to determine whether personal protective equipment (PPE) must be used. PPE must meet applicable American National Standards Institute (ANSI) standards, and be properly used and maintained. The employer must establish appropriate safety and health practices, in compliance with applicable state and federal laws, for these procedures and associated job site hazards. Hazardous materials must be addressed in a Hazard Communication program, and Material Safety Data Sheets (MSDS) must be obtained and available to workers. Supervisors and employees should be aware of job site hazards, and comply with their employers safety and health program. The following table identifies some areas that may affect individuals performing the procedures in this manual.

Body Part Affected	Potential Hazards	PPE/Procedures That May Be Appropriate
Head	Falling or fixed overhead objects; electrical shock	Hard hat or other protective helmet
Eyes and Face	Flying objects, radiation, molten metal, chemicals	Safety glasses, goggles, face shields; prescription or filter lenses
Ears	Noise	Ear plugs, ear muffs
Respiratory System	Inhalation of dusts, chemicals; O_2 deficiency	Properly fit and used respiratory protection consistent with the hazard
Skin	Chemicals including cement; heat	Appropriate chemical or heat resistant gloves, long-sleeve shirts, coveralls
Mouth, digestive system	Ingestion of toxic materials	Disposable or washable gloves, coveralls; personal hygiene
Hands	Physical injury (pinch, cut, puncture), chemicals	Appropriate gloves for physical hazards and compatible with chemicals present
Feet	Falling, sharp objects; slippery surfaces, chemicals	Safety shoes or boots (steel toed, steel shank); traction soles; rubber boots – chemicals, wet conditions
Joints, muscles, tendons	Lifting, bending, twisting, repetitive motions	Proper training and procedures; procedure modifications
Body/Torso	Falls; Burial	Fall protection; trench sloping or shoring
Miscellaneous	Traffic	Visibility, awareness, communication; driver training, safety awareness
Whole body	Radiation	Radiation safety training

RANDOM SAMPLING OF CONSTRUCTION MATERIALS

01 Significance

Sampling and testing are two of the most important functions in quality control (QC). Data from the tests are the tools with which the quality of product is controlled. For this reason, great care must be used in following standardized sampling and testing procedures.

In controlling operations, it is necessary to obtain numerous samples at various points along the production line. Unless precautions are taken, sampling can occur in patterns that can create a bias to the data gathered. Sampling at the same time, say noon, each day may jeopardize the effectiveness of any quality program. This might occur, for example, because a material producer does certain operations, such as cleaning screens at an aggregate plant, late in the morning each day. To obtain a representative sample, a reliable system of random sampling must be employed.

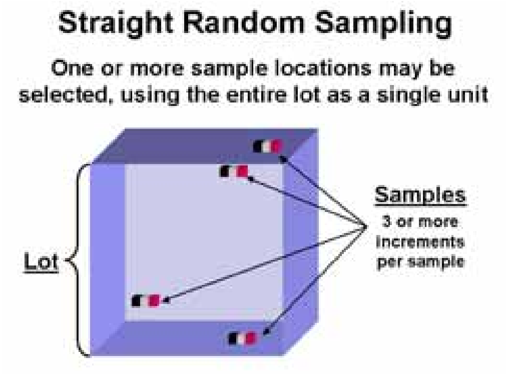
02

Scope

The procedure presented here eliminates bias in
sampling materials. Randomly selecting a set of
03 numbers from a table or calculator will eliminate
04 the possibility for bias. Random numbers are used
to identify sampling times, locations, or points
within a lot or sublot. This method does not cover
how to sample, but rather how to determine
sampling times, locations, or points.

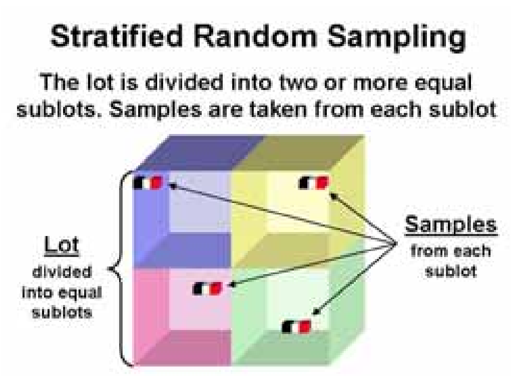
Sampling Concepts

A lot is the quantity of material evaluated by QC
05 procedures. A lot is a preselected quantity that
may represent hours of production, a quantity or
number of loads of material, or an interval of time.



A lot may be comprised of several portions that are called sublots or units. The number of sublots comprising a lot will be determined by the agency's specifications.

06 **Straight Random Sampling vs. Stratified Random Sampling:** Straight random sampling considers an entire lot as a single unit and determines each sample location based on the entire lot size. Stratified random sampling divides the lot into a specified number of sublots or units and then determines each sample location within a distinct sublot. Both methods result in random distribution of samples to be tested for compliance with the agency's specification.



Agencies stipulate when to use straight random sampling or stratified random sampling. AASHTO T 2, Sampling of Aggregates, for
07 example, specifies a straight random sampling procedure.

Picking Random Numbers from a Table

Table 1 contains pairs of numbers. The first
08 number is the "pick" number and the second is the Random Number, "RN". The table was generated with a spreadsheet and the cells (boxes at the intersection of rows and columns) containing the RNs actually contain the "random number function". Every time the spreadsheet is opened or changed, all the RNs change.

1. Select a Pick number in a random method. The first two or last two digits in the next automobile license plate you see would be one way to select. Another would be to start a digital stop watch and stop it several seconds later, using the decimal part of the seconds as your Pick number.
2. Find the RN matching the Pick number.

Picking Random Numbers with a Calculator

09 Many calculators have a built-in random number function. To obtain a random number, key in the code or push the button(s) the calculator's instructions call for. The display will show a number between 0.000 and 1.000 and this will be your random number.

TABLE 1
Random Numbers

Pick	RN	Pick	RN	Pick	RN	Pick	RN	Pick	RN
01	0.998	21	0.758	41	0.398	61	0.895	81	0.222
02	0.656	22	0.552	42	0.603	62	0.442	82	0.390
03	0.539	23	0.702	43	0.150	63	0.821	83	0.468
04	0.458	24	0.217	44	0.001	64	0.187	84	0.335
05	0.407	25	0.000	45	0.521	65	0.260	85	0.727
06	0.062	26	0.781	46	0.462	66	0.815	86	0.708
07	0.370	27	0.317	47	0.553	67	0.154	87	0.161
08	0.410	28	0.896	48	0.591	68	0.007	88	0.893
09	0.923	29	0.848	49	0.797	69	0.759	89	0.255
10	0.499	30	0.045	50	0.638	70	0.925	90	0.604
11	0.392	31	0.692	51	0.006	71	0.131	91	0.880
12	0.271	32	0.530	52	0.526	72	0.702	92	0.656
13	0.816	33	0.796	53	0.147	73	0.146	93	0.711
14	0.969	34	0.100	54	0.042	74	0.355	94	0.377
15	0.188	35	0.902	55	0.609	75	0.292	95	0.287
16	0.185	36	0.674	56	0.579	76	0.854	96	0.461
17	0.809	37	0.509	57	0.887	77	0.240	97	0.703
18	0.105	38	0.013	58	0.495	78	0.851	98	0.866
19	0.715	39	0.497	59	0.039	79	0.678	99	0.616
20	0.380	40	0.587	60	0.812	80	0.122	00	0.759

Examples of Straight Random Sampling Procedures Using Random Numbers

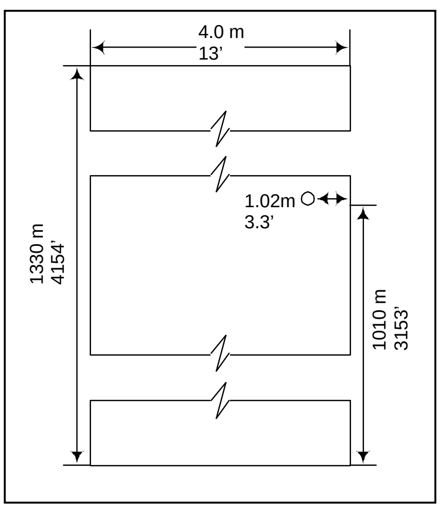
10 **Sampling from a Belt or Flowing Stream:** Agencies specify the frequency of sampling in terms of time, volumes, or masses. The specification might call for one sample from every 1,000,000 kg(1000 t) or 1100 Tons(T) of aggregate. If the random number was 0.317, the

sample would be taken at (0.317)(1,000,000 kg) = 317,000 kg (317 t). Or (.317) (1100 T) = 349 T.

One sample per day might also be specified. If the day were 9 hours long and the random number 0.199, the sample would be taken at (0.199)(9 hrs) = 1.79 hr = 1 hr, 48 minutes into the day. AASHTO T 2 permits this time to be rounded to the nearest 5 minutes.

11 **Sampling from Haul Units:** Based on the agency's specifications – in terms of time, volume, or mass – determine the number of haul units that comprise a lot. Multiply the selected random number(s) by the number of units to determine which unit(s) will be sampled.

For example, if 20 haul units comprise a lot and one sample is needed, pick one RN. If the RN were 0.773, then the sample would be taken from the (0.773) (20) = 15.46, or 16th haul unit.



Sampling from a roadway

12 **Sampling from a Roadway with Previously Placed Material:** The agency's specified frequency of sampling – in time, volume, or mass – can be translated into a location on a job. For example, if a sample is to be taken every 800 m^3 (1000yd^3) and material is being placed 0.15 m (0.50') thick and 4.0 m (13') wide, then the lot is 1330 m (4154') long. You would select two RNs in this case. To convert yd^3 to ft^3 multiply by 27.

13 The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the

14 sample would be taken. For example, a first RN of 0.759 would specify that the sample would be taken at (0.759)(1330 m) or (4154') = 1010 m or 3153'from the beginning. A second RN of 0.255

15 would specify that the sample would be taken at (0.255)(4.0 m) or (13') = 1.02 m or 3.3'from the

right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1') to the edge. If the RN specifies a location closer than 0.3 m (1'), then 0.3 m (1') is added to or subtracted from the distance calculated.

16 **Sampling from a Stockpile:** AASHTO T 2 recommends against sampling from stockpiles. However, some agencies use random procedures in determining sampling locations from a stockpile. Bear in mind that stockpiles are prone to segregation and that a sample obtained from a stockpile may not be representative. Refer to AASHTO T 2 for guidance on how to sample from a stockpile.

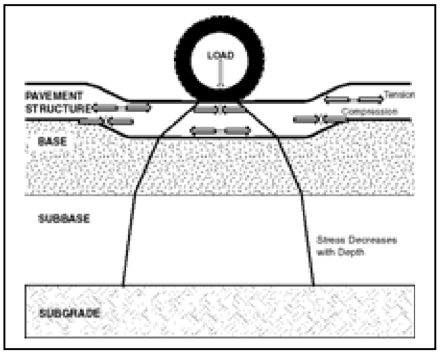
17 **In-Place Density Testing:** Agency specifications will indicate the frequency of tests. For example, one test per 500 m^3 (666 yd^3) might be required. If the material is being placed 0.15 m (0.50') thick and 10.0 m (33') wide, then the lot is 333 m (1090') long. You would select two RNs in this case.

18

The first RN would be multiplied by the length to determine where the sample would be taken along the project. The second would be multiplied by the width to determine where, widthwise, the sample would be taken. For example, a first RN of 0.387 would specify that the sample would be taken at (0.387)(333 m) or (1090') = 129 m or (422') from the beginning. A second RN of 0.588 would specify that the sample would be taken at (0.588)(10.0 m) or (33') = 5.88 m or (19') from the
19 right edge of the material. To avoid problems associated with taking samples too close to the edge, no sample is taken closer than 0.3 m (1') to the edge. If the RN specifies a location closer than 0.3 m (1'), then 0.3 m (1') is added to or subtracted from the distance calculated.

BASICS OF COMPACTION AND DENSITY CONTROL

01 Introduction



Load distribution in roadway cross section

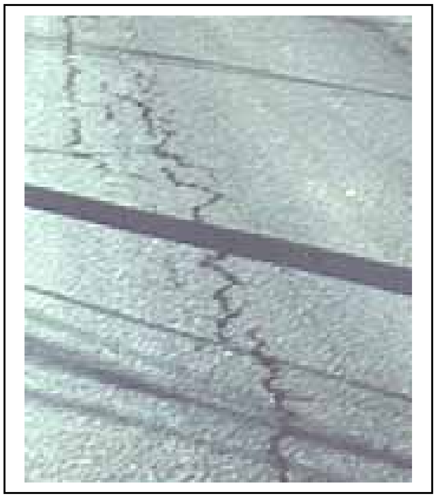
02 Roadways are constructed in layers. The first layer
is the subgrade, or naturally present material. Next
comes the subbase, material usually having better
03 structural, drainage, and other properties than the
subgrade. This material is sometimes a select
material. Above the subbase is placed the base,
material of even better quality than the subbase.
Finally there is the pavement consisting of either
hot mix asphalt (HMA) or portland cement concrete
(PCC). In this layered system, structural or load
bearing properties improve as we move up from
subgrade to pavement. The result is a roadway
structure that supports traffic without undergoing
excessive surface deflection and/or long term
settlement.

Variations to this layering can occur as in roadways constructed on high quality subgrade in which the subbase layer is eliminated. Also to be considered is “embankment”, material between the naturally occurring subgrade and the subbase or base, that is added in “fill” sections of the roadway where the finished road is substantially above original grade.

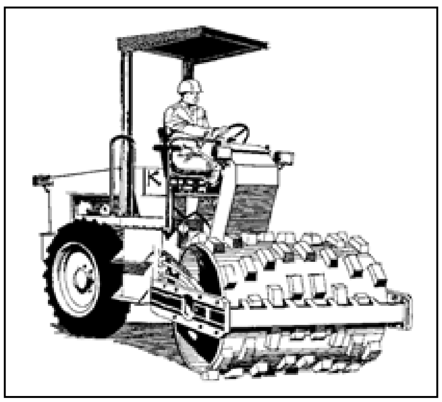
Grading

04 Stability and durability of roadways is greatly
dependent on the finished density of the various
components. Low-density subgrade, subbase, base,
05 or embankment will lead to excessive surface
deflection under load and/or long term settlement in
an amount higher than anticipated. However,
compacting these elements to densities higher than
necessary is expensive in both time and money.

Quality of roadways also depends greatly on the pavement. In HMA roadways, the density of the HMA plays a significant role in the overall ability to support load and provide long term service. HMA pavement specifications include detail on density as well as percent voids. Under-compaction



Cracking



Sheepsfoot roller

Steel roller

06 results in low density and high void content. An
under-compacted pavement will have low strength,
reduced durability, high deformation, and high
permeability leading to problems such as rutting,
ravelling, and freeze-thaw damage. Over-
07 compaction results in high density and low void
content. This pavement may bleed, rut, crack, or
have premature failure.

For these reasons, a basic understanding of
compaction theory and a thorough knowledge of
testing methods is necessary for those involved with
08 construction of embankments and bases, as well as
HMA pavement. Compaction equipment and
techniques depend on the type of material.
Cohesive soils, such as clay, and cohesionless soils,
such as gravel, require different compaction
methods, and different equipment may be used on
HMA than on soils.

09 Fine-Grained Soils

For fine-grained soils that contain a significant amount of cohesion and little or no internal friction, density depends on compactive effort and moisture content. With these soils, moisture-density relations are key, and two similar test methods are used to determine the relationship between soil moisture and density.

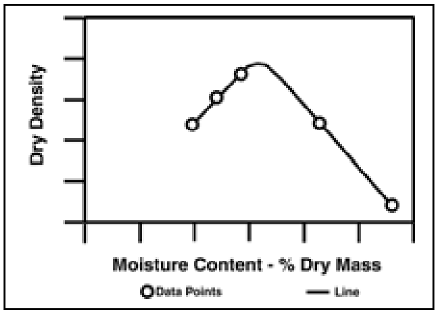
- AASHTO T 99, the standard Proctor test
- AASHTO T 180, the modified Proctor test

10

In both methods, samples of soil are prepared at
11 several moisture contents and compacted into
molds of specified sizes using manual or
mechanical rammers delivering a specified quantity
12 of compactive energy. Knowing the moist masses
of the compacted samples and the volume of the
13 molds, moist densities can be determined. Moisture
contents of the compacted samples are determined
and used to obtain dry density values for the same
samples. Maximum dry density and optimum
moisture content for the soil are determined by
14 plotting the relationship between dry density and
moisture content.

15

16



Moisture-density curve

Construction specifications generally require that the soil be compacted to some percentage of maximum dry density while being maintained at a moisture content close to the optimum. These specified values will be based on AASHTO T 99, or AASHTO T 180 depending on the agency. In the field, dry density and moisture content of the material will be determined using a nuclear moisture-density gauge. The field values will be compared to the specifications to determine conformance with the project requirements.

Coarse-Grained Soils

17

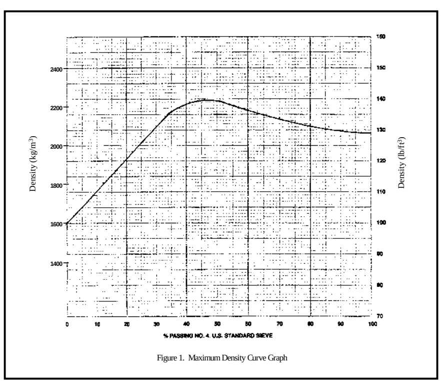
Nuclear moisture-density gauge

For coarse-grained granular soils having little or no cohesion, compactive effort is the primary concern, and moisture content is not as significant an issue because these soils are free-draining and do not retain water. These soils are tested using two general classifications of procedures. The first includes the moisture-density methods discussed above under “Fine-grained Soils.” The second includes procedures that relate density to gradation.

Granular, free-draining materials can be tested by procedures that combine compaction and vibration, as in the Relative Density test. However, various transportation agencies have developed specialized tests that are a hybrid of moisture-density test procedures and relative density determinations, including the following:

18

- AKDOT&PF’s ATM-12
- ITD’s T-74
- WSDOT’s TM 606
- WFLHD’s Humphrys



19

20

Maximum density curve

In these tests, material is compacted in a mold and in a manner similar to those used in a Proctor test, after which the material is further compacted through a combination of applied loads and vibration. A laboratory maximum dry density is determined, as is the percent of material passing a certain sieve such as the No. 4. A number of determinations are made for different percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the

percentage of material passing that sieve. These
21 tests are conducted in the agency's central lab, and
the curve developed is a central lab function.

Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM-12, T-74, TM 606, and Humphry's depending on the agency. In the field, the density of the granular material will be determined using a nuclear moisture-density gauge. The percent of material passing the specified sieve will also be determined. These values will be compared with the curve developed in the lab to determine conformance with the project specifications.

Correction for Oversize Material

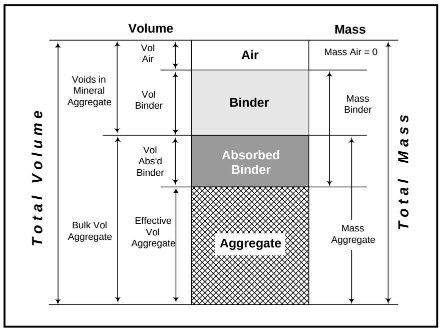
Coarse and fine material

22 AASHTO T 99, and AASHTO T 180 discussed
above are conducted on materials below a certain
size, either No. 4 or 3/4-in. depending on the
method. If the material to be tested includes
23 particles in excess of that size, corrections will be
required to the maximum dry densities determined.
The method used is AASHTO T 224, Correction for
Coarse Particles in the Soil Compaction Test.

The corrected density is actually a weighted average of the density of the smaller material passing the specified sieve and the larger material retained on the sieve. The density of the smaller material is determined using one of the methods covered above. The density of the larger material is based on knowledge of its bulk specific gravity.

Hot Mix Asphalt Pavement

24 For HMA, density depends on compactive effort as well as the mix design. The gradation and particle shape of the aggregate, the grade of asphalt binder, and the interaction of these have major influences on density and percent voids. The level of compactive effort and the equipment used depend on the mix design properties, environmental conditions and lift thickness.



HMA phase diagram

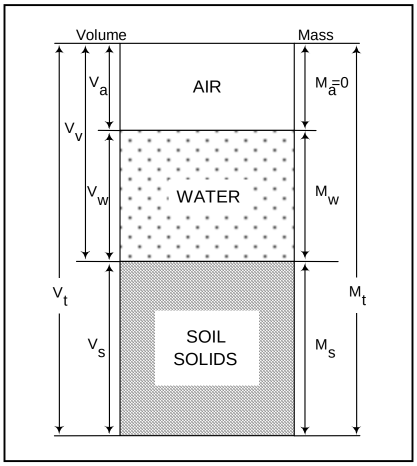
25 Construction specifications will call for obtaining a certain percentage of maximum voidless density, as determined in the mix design process, while maintaining voids within a certain range. A specification of 92 to 96 percent of maximum density and a corresponding void content between 8
26 and 4 percent is typical. In the field, the density of the compacted HMA will be determined with cores and/or calibrated nuclear density gauges and, with this information, the percent voids will be calculated. These values will be compared to the specifications to determine conformance with the project requirements.

Summary

27 Proper compaction of soil, aggregate, and hot mix asphalt is necessary for high-quality roadways. Understanding and proper performance of standardized density tests are paramount in obtaining that compaction. The Embankment and Base and/or In-Place Density technician must obtain samples and perform tests in the accepted manner in order to assure the quality of the finished roadway.

TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS FOP FOR AASHTO T 265



Phase diagram

Apparatus

Significance

01 The amount of water contained in many materials influences design and construction practices. Road bases are difficult to compact if they are too dry or 02 too wet. If too dry, water must be added, and the amount to be added depends on how much is already present.

03

Scope

This procedure covers the determination of moisture content of aggregate and soil in accordance with AASHTO T 255 and AASHTO T 265. It may also be used for other construction materials.

Apparatus

04

- Balance or scale: capacity sufficient for the principle sample mass, accurate to 0.1 percent of sample mass or readable to 0.1 g. Meeting the requirements of AASHTO M 231.
- Containers, capable of being sealed
- Suitable drying containers
- Microwave safe containers
- Thermometer reading to 400 ±10°F
- Heat source , controlled
  – Forced draft oven
  – 05 Ventilated / convection oven
- Heat source, uncontrolled
  – Microwave oven (600 watts minimum)
  – Infrared heater, hot plate, fry pan, or any other device/method that will dry the sample without altering the material being dried
- Utensils such as spoons
- Hot pads or gloves

06 **Sample Preparation**

For aggregate, select the proper sample size based on Table 1 or other information that may be specified by the agency. Obtain the sample in accordance with the FOP for AASHTO T 2.

Immediately seal or cover samples to prevent any change in moisture content.

07 **TABLE 1**

Sample Sizes for Moisture Content of Aggregate

Nominal Maximum Size* (in.)	Minimum Sample Mass g (lb)
No. 4	500 (1.1)
3/8	1500 (3.3)
1/2	2000 (4)
3/4	3000 (7)
1	4000 (9)
1½	6000 (13)
2	8000 (18)
2½	10,000 (22)
3	13,000 (29)
3½	16,000 (35)
4	25,000 (55)
6	50,000 (110)

***** One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum.

For soil, select the proper sample size based on Table 2 or other information that may be supplied by the agency.

TABLE 2

Sample Sizes for Moisture Content of Soil

08

Maximum Particle Size (in)	Minimum Sample Mass g
No. 40	10
No. 4	100
1/2	300
1	500
2	1000

Procedure

For aggregate, determine and record all masses to
09 the nearest 0.1 percent of the sample mass or to the nearest 0.1 g. For soil, determine and record all masses to the nearest 0.1 g.

10 1. Determine and record the mass of the container.
2. Place the wet sample in the container, and record the total mass of the container and wet sample.
3. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 2.
4. Dry the sample to a constant mass in accordance with the directions given under Directions for Drying below. Measures will be taken to protect the scale from excessive heat while determining constant mass.

5. Allow the sample to cool and record the total mass of the container and dry sample.
6. Determine the dry mass of the sample by subtracting the mass in Step 1 from the mass in Step 5.

Directions for Drying Aggregate

Forced Air Oven

11 • Controlled - Forced Draft, Ventilated, or Convection Oven

12
1. Spread sample in the container
2. Dry to constant mass at 230 ±9°F. Constant mass has been reached when there is less than a 0.10 percent change after an additional 30 minutes of drying.

• Uncontrolled

13

Where close control of temperature is not required (such as with aggregate not altered by higher temperatures, or with aggregate that will not be used in further tests, or where precise information is not required), higher temperatures or other suitable heat sources may be used. Other heat sources may include microwaves, hot plates, or heat lamps.

14 - Microwave Oven

1. Heap sample in pile in the center of the container and cover. This cover must allow moisture to escape.
2. Dry to constant mass. Constant mass has been reached when there is **<u>less than</u>** 0.10 percent change after at least an additional 10 minutes of drying.

Caution: Some minerals in the sample may cause the aggregate to overheat altering the aggregate gradation.

15 - Hot plate, heat lamp, etc.

1. Spread sample in container.
2. Stir the sample frequently to avoid localized overheating and aggregate fracturing.
3. Dry to a constant mass. Constant mass has been reached when there is **less than** 0.10 percent change after at least an additional 20 minutes of drying.

Directions for Drying Soil

16 • Oven (Preferably Forced Draft/Air)

1. Place sample in container.
2. Dry to constant mass at 230 ±9°F. Constant mass has been reached when there is no change after an additional 1 hour of drying. A sample dried overnight (15 to 16 hours) is sufficient in most cases.

Note 1: Soils containing gypsum or significant amounts of organic material require special drying. For reliable moisture contents dry these soils 140°F. For more information see FOP for AASHTO T 265, Note 2.

Calculation

Constant Mass:

Calculate constant mass using the following formula: 17

$$\frac{Mp - Mn}{Mp} x100 = \%Change$$

Where: M_p = previous mass measurement

M_n = new mass measurement

Example:

Mass of container: 1232.1 g
Mass of the container & sample after first drying cycle: 2637.2 g 18
Mass, M_p, of possibly dry sample: 2637.2 g - 1232.1 g = 1405.1 g
Mass of container and dry sample after second drying cycle: 2634.1 g
Mass, M_n, of dry sample: 2634.1 g - 1232.1 g = 1402.0 g

$$\frac{1405.1 - 1402.0}{1405.1} \times 100 = 0.22$$

0.22% is not less than 0.10%, so continue drying

Mass of container and dry sample after third drying cycle: 2633.0 g
Mass, M_n, of dry sample: 2633.0 g - 1232.1 g = 1400.9 g 19

$$\frac{1402.0 - 1400.9}{1402.0} \times 100 = 0.08$$

0.08% is less than 0.10% constant mass has been reached for an aggregate, but continue drying for soil.

Moisture Content: 20

Calculate the moisture content, as a percent, using the following formula:

$$\frac{M_W - M_D}{M_D} \times 100 = w$$

where: w = moisture content, percent

M_W = wet mass

M_D = dry mass

Example:

Mass of container: 1232.1 g 21
Mass of container and wet sample: 2764.7 g
Mass, M_W, of wet sample: 2764.7 g - 1232.1 g = 1532.6 g
Mass of container and dry sample **(COOLED)**: 2633.1 g
Mass, M_D, of dry sample: 2633.1 g - 1232.1 g = 1401.0 g

$$w = \frac{1532.6\,g - 1401.0\,g}{1401.0\,g} \times 100 = \frac{131.6\,g}{1401.0\,g} \times 100 = 9.39\% \text{ rounded to } 9.4\%$$

22

Report

Results shall be reported on standard forms approved for use by the agency. Include:

- M_W, wet mass
- M_D, dry mass
- w, moisture content to nearest 0.1 percent

Tips! 23

- Let the sample cool before determining final dry mass.
- Divide by M_D, not M_W.

REVIEW QUESTIONS

1. What extra care should be taken when using a microwave to dry aggregates?

2. What are the maximum temperatures that a sample should be allowed to attain when using the various types of ovens?

3. How is "constant mass" defined according to this FOP:

   For Aggregate?

   For Soil?

PERFORMANCE EXAM CHECKLIST

TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255
LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS FOP FOR AASHTO T 265

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Representative sample of appropriate mass obtained?	_____	_____
2. Mass of container determined to 0.1 g?	_____	_____
3. Sample placed in container and mass determined to 0.1 g?	_____	_____
4. Test sample mass conforms to the required mass?	_____	_____
5. Wet sample mass determined to 0.1 g?	_____	_____
6. Loss of moisture avoided prior to mass determination?	_____	_____
7. Sample dried by a suitable heat source?	_____	_____
8. If aggregate heated by means other than a controlled oven, is sample stirred to avoid localized overheating?	_____	_____
9. For aggregate: if other than a forced draft, microwave or conventional oven, is aggregate heated for an additional 20 minutes and then mass determined and compared to previous mass – showing less than 0.10 percent loss?	_____	_____
10. For soil: Is soil heated for an additional 1 hour and then mass determined and compared to previous mass - showing no loss?	_____	_____
11. Sample cooled, dry mass determined & recorded to the nearest 0.1 percent?	_____	_____
12. Moisture content calculated correctly and recorded to the nearest 0.1 percent?	_____	_____

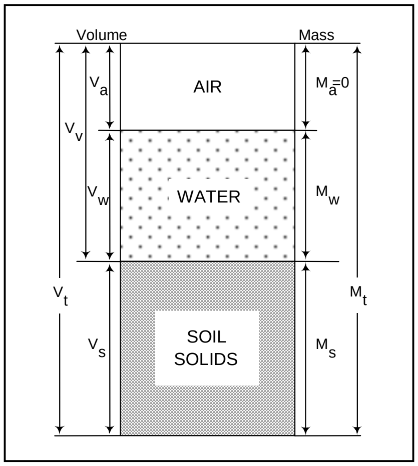
Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

____
____
____
____

Examiner Signature ______________________________WAQTC #:______________

DETERMINATION OF MOISTURE IN SOILS BY MEANS OF CALCIUM CARBIDE GAS PRESSURE MOISTURE TESTER

FOP FOR AASHTO T 217



Phase diagram

Significance

Moisture content of soils is a significant parameter in compaction. Soil is best compacted at or near
01 what is called optimum moisture content. Soils that are too dry will need to have water added. Soils
02 that are too wet will need to be dried prior to compacting. For these reasons, moisture content must be determined in the field in a timely manner.

This test procedure is particularly useful in the field in that the apparatus used is portable and no utilities
03 are required. The "Speedy Moisture Tester," as the equipment is known, quickly determines moisture content as part of a chemical reaction between water and calcium carbide.

Scope

04 This procedure uses a calcium carbide gas pressure moisture tester to determine the moisture content of soils in accordance with AASHTO T 217. This FOP does not apply to the Super 200 D tester (see
05 AASHTO 217).

<u>CAUTION</u>: This procedure involves a potentially dangerous chemical reaction. When calcium carbide reacts with water, acetylene gas is produced. Breathing the acetylene gas and running the test where potential for sparks or other ignition might cause a fire must be avoided.

06 ### Apparatus

- Calcium carbide gas pressure moisture tester
- Balance or scale, conforming to the requirements for AASHTO M 231 and having a capacity of 2 kg and sensitive to 0.1 g. Most testers include a balance built into the transportation container.

- Cleaning brush and cloth.
- Scoop (or cap built into unit) for putting the soil sample into the pressure chamber. Some testers include a cap built into the unit.
- Steel balls, 1.25” diameter

Material

- Calcium carbide reagent meeting the
07 requirements of AASHTO T 217.

Note 1: Check the manufacturer’s recommendations for maximum storage life and replacement, and storage requirements. A change in color is an indicator of age.

Procedure

Adding calcium carbide

08 1. With the moisture tester in a horizontal position
09 place three scoops, approximately 24 g, of calcium carbide, into the body.
2. Place two steel balls into the body of the tester
10 with the calcium carbide.
3. Obtain a sample of soil of the wet mass specified by the manufacturer, using the balance built into the unit, and place the soil into the cap of the tester.

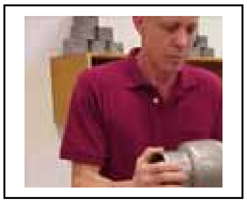
Note 2: This method shall not be used on granular material having particles large enough to affect the accuracy of the test. In general, no + No. 4 material.

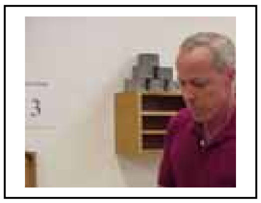
Note 3: If the anticipated moisture content exceeds the capacity of the instrument being used, then one-half of the specified soil mass should be placed into the unit, and the resulting gauge reading multiplied by two.

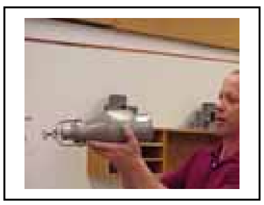
Adding soil

4. With the instrument in a horizontal position, so that calcium carbide does not come into contact with the soil, seat the cap on the body and
11 tighten down on the clamp, thereby sealing the tester.
12 5. Carefully turn the unit to vertical and gently tap to allow the soil to fall from the cap into the pressure vessel. Do not allow the steel balls to strike the bottom of the pressure vessel.
6. Return vessel to horizontal position. Create a circular motion that causes the steel balls to roll

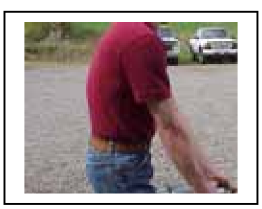
Sealing Tester







Reading gauge



around the interior perimeter of the vessel. Do
13 not allow the steel balls to hit the cap or the bottom of the pressure vessel. Continue this motion vigorously for 60 seconds, then rest for
14 30 seconds. Repeat motion and resting cycles a minimum of three times or until no further reaction occurs.

7. Allow time for the dissipation of the heat
15 generated by the chemical reaction.

16 8. When the gauge needle stops moving, take a reading while holding the unit in a horizontal
17 position at eye level.

18 9. Record the sample mass and the gauge reading.

19 10. Position the unit so that the cap is away from
20 the user and slowly loosen the clamp to release the gas from the pressure chamber. Inspect the
21 sample inside the pressure chamber. If it is not
22 completely pulverized, a new sample must be obtained and tested after the instrument has been thoroughly cleaned.

Moisture Determination

1. The tester determines moisture content based on
23 the wet mass of the soil. Moisture content based on the dry mass of soil is obtained from a conversion chart or curve supplied with each tester. See Figure 1 for curve from AASHTO T 217.

Note 4: Check the accuracy of the gauge and the conversion chart or curve periodically, in accordance with agency requirements, by testing samples of a known moisture content. Develop correction factors, if necessary.

Example:

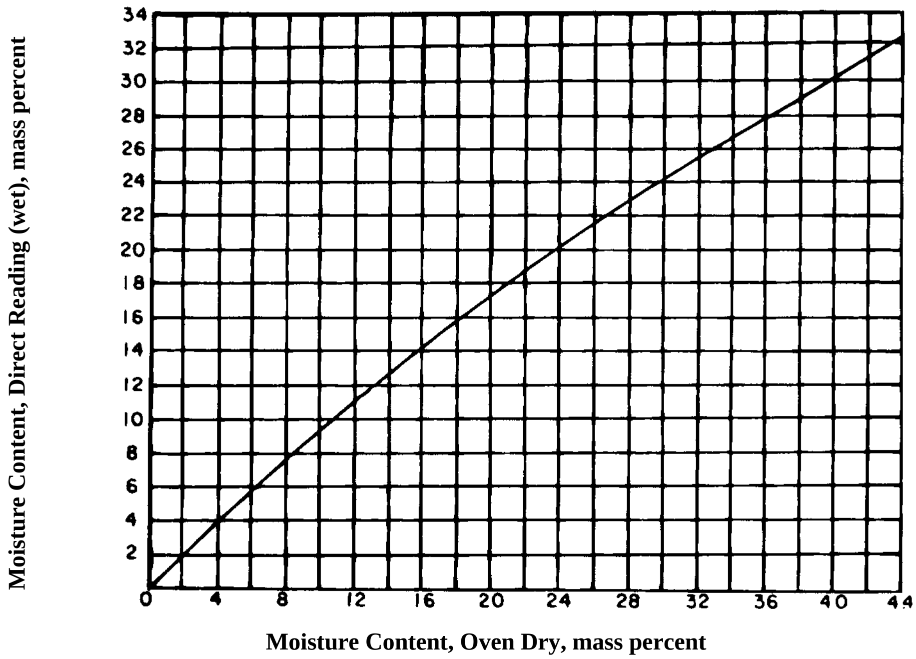
Gauge reading: 18.5

Conversion from chart: 22.1

Recorded % moisture: 22%

Figure 1. Conversion Curve for Moisture Tester

24



25 Report

Results shall be reported on standard forms approved by the agency. Report moisture content to the nearest 1 percent.

Tips!

26

- Follow the safety precautions suggested by the tester's manufacturer and by the maker of the calcium carbide reagent.
- Do not allow the steel balls to hit the cap or bottom of the pressure vessel.
- Remember to use the conversion chart or curves to determine moisture content based on dry mass of soil.

REVIEW QUESTIONS

1. For how long can calcium carbide be used? Indefinitely?

2. What safety precautions need to be taken in performing the test procedure?

3. How is moisture content related to the gauge reading?

4. For how long should the circular motion of the vessel continue?

5. After motion is completed, but before reading the gauge, what should be done?

6. What is the reported moisture content when your gauge reading is 14.6?

PERFORMANCE EXAM CHECKLIST

DETERMINATION OF MOISTURE IN SOILS BY MEANS OF CALCIUM CARBIDE GAS PRESSURE MOISTURE TESTER FOP FOR AASHTO T 217

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Shelf life of calcium carbide reagent checked?	_____	_____
2. Correct amount of reagent placed in body of vessel?	_____	_____
3. The correct number and size of steel balls introduced into the vessel?	_____	_____
4. Correct mass of moist soil placed in cap of vessel?	_____	_____
5. Cap clamped to body with vessel in horizontal position?	_____	_____
6. Soil allowed to fall from cap?	_____	_____
7. Motion performed properly (60 seconds, rest for 30 seconds, for up to three cycles)?	_____	_____
8. Motion performed without steel balls hitting cap or bottom of vessel?	_____	_____
9. Vessel allowed to cool?	_____	_____
10. Gauge on vessel stops moving.	_____	_____
11. Reading taken with vessel in horizontal position at eye level?	_____	_____
12. Sample mass and gauge reading recorded?	_____	_____
13. Tester positioned with cap away from user before gases slowly released?	_____	_____
14. Contents inspected for complete pulverization?	_____	_____
15. Gauge reading on wet mass basis converted to dry mass percent to nearest 1%?	_____	_____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

____
____
____
____
____
____
____

Examiner Signature ___________________________ WAQTC #:_______________

MOISTURE-DENSITY RELATIONS OF SOILS:

USING A 2.5 kg (5.5-lb) RAMMER AND A 305 mm (12 in.) DROP FOP FOR AASHTO T 99

USING A 4.54-kg (10 lb) RAMMER AND A 457 mm (18 in.) DROP FOP FOR AASHTO T 180

Significance

01 The density, or degree of compaction, of soil or
02 soil-aggregate mixtures has a significant influence
on the stability and durability of roadways. Low
density subgrade, subbase, base or embankment
will lead to excessive deflection under load and/or
long term settlement in an amount higher than
anticipated. Obtaining proper density depends on
two major factors: compactive effort and moisture
03 content.

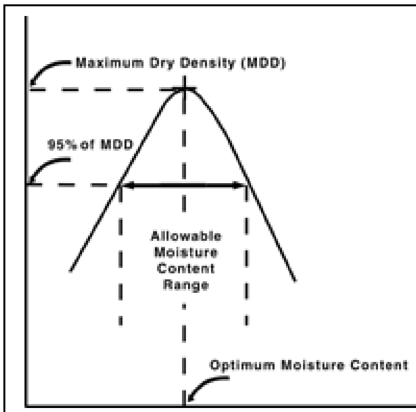
04 Compactive effort relates to the type and weight of
compaction equipment, along with the thickness of
the "lift" being compacted and the number of times
each lift is passed over by the compaction
equipment. Equipment includes static and vibratory
rollers, smooth and sheepsfoot steel rollers, and
pneumatic tire rollers of varied weights yielding
05 many different compactive efforts.

06 Density also depends upon moisture content. The
moisture content corresponding to maximum dry
density of the soil or soil-aggregate mixture under a
given compactive effort is known as optimum water
content. As the water content increases or
decreases from this optimum value, the dry density
07 decreases.

Agency specifications commonly require that a
certain percentage of maximum dry density be
obtained while the moisture content of the soil or
08 soil-aggregate mixture is held within certain limits.
For example, a specification might call for 95
percent of maximum dry density with a moisture
content of the optimum value ±2 percent. For these
reasons, it is critical to understand the various test
methods and equipment used in determining the
moisture-density relations of soil.

Steel roller

Adding water

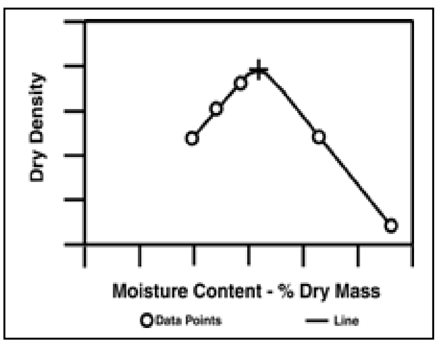


Moisture vs. dry density

Scope

This procedure covers the determination of the moisture-density relations of soils and soil-aggregate mixtures in accordance with two similar test methods:

09
- AASHTO T 99 methods A, B, C & D
- AASHTO T 180 methods A, B, C & D



Optimum water content

This test method applies to soil mixtures having 40% or less retained on the No. 4 sieve for methods A or B, or, 30 % or less on the 3/4 in. with methods C or D. The retained material is defined as oversize
10 (coarse) material. If no minimum percentage is specified 5 % will be used. Samples that contain
11 oversize (coarse) that meet the percent retained criteria should be corrected by using the FOP for AASHTO T 224. Samples of soil or soil-aggregate mixture are prepared at several moisture contents and compacted into molds of specified size using manual or mechanical rammers delivering a specified quantity of compactive energy. The moist masses of the compacted samples are divided by the volume of the mold to determine moist density values. Moisture contents of the compacted samples are determined and used to obtain the dry density values of the same samples. Maximum dry density and optimum moisture content for the soil or soil-aggregate mixture is determined by plotting the relationship between dry density and moisture content.

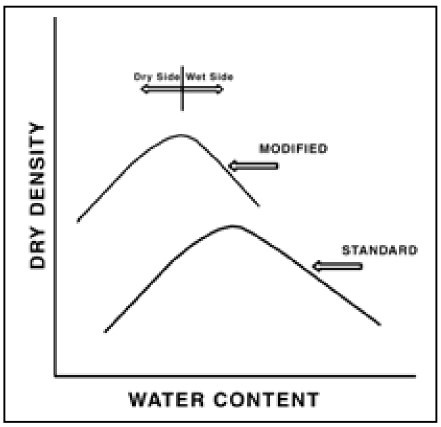
Molds and Rammer

12

13

Apparatus

- Mold – Cylindrical, made of metal and having the dimensions shown in Table 1 or Table 2. It shall include a detachable collar and a base plate to which the mold can be fastened. If permitted by the agency, the mold may be of the "split" type, consisting of two half-round sections, which can be securely locked in place to form a cylinder.



14

- Rammer –Manually or mechanically operated rammers as detailed in Table 1 or Table 2. A manually operated rammer shall be equipped with a guide-sleeve to control the path and height of drop. The guide-sleeve shall have at least four vent holes no smaller then 3/8 in. diameter, spaced approximately 90 degrees apart and approximately 3/4 in. from each end. A mechanically operated rammer will uniformly distribute blows over the sample and will be calibrated with several soil types, and be adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. For additional information concerning calibration, see the FOP for AASHTO T 99 and T 180.
- Sample Extruder – A jack, lever frame, or other device for extruding compacted specimens from the mold quickly and with little disturbance.

Sample extruder

15

- Balance(s) or scale(s) of the capacity and sensitivity required for the procedure used by the agency.
- A balance or scale with a capacity of 20 kg (45 lb) and a sensitivity of 5 g (0.01 lb) for obtaining the sample. Meeting the requirements of AASHTO M 231.
- A balance or scale with a capacity of 2 kg and a sensitivity of 0.1 g, is used for moisture content determinations done under both procedures. Meeting the requirements of AASHTO M 231.

- Drying Apparatus – A thermostatically controlled drying oven capable of maintaining a temperature of 230 ±9°F for drying moisture content samples in accordance with the FOP for AASHTO T 255/T 265.

16

- Straightedge – A steel straightedge at least 10 in. long, having one beveled edge and at least one surface, used for final trimming, plane within 0.1 percent of its length.

No. 4 sieve - Straight edge

- Sieve(s): No. 4 and/or 3/4 in. conforming to AASHTO M 92.
- Mixing Tools – Miscellaneous tools such as a mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device, for mixing the sample with water.
- Containers with close-fitting lids to prevent gain or loss of moisture in the sample.

Table 1 17

Comparison of Apparatus, Sample, and Procedure - Metric

	T 99	T 180
Mold Volume, m^3	Methods A, C: 0.000943	Methods A, C: 0.000943
	Methods B, D: 0.002124	Methods B, D: 0.002124
Mold Diameter, mm	Methods A, C: 101.6	Methods A, C: 101.6
	Methods B, D: 152.4	Methods B, D: 152.4
Mold Height, mm	116.43	116.43
Detachable Collar Height, mm	51	51
Rammer Diameter, mm	50.80	50.80
Rammer Mass, kg	2.495	4.536
Rammer Drop, mm	305	457
Layers	3	5
Blows per Layer	Methods A, C: 25	Methods A, C: 25
	Methods B, D: 56	Methods B, D: 56
Material Size, mm	Methods A, B: 4.75 minus	Methods A, B: 4.75 minus
	Methods C, D: 19.0 minus	Methods C, D: 19.0 minus
Test Sample Size, kg	Method A: 3 Method B: 7 Method C: 5 (1) Method D: 11(1)	
Energy, kN-m/m^3	592	2,693

Table 2

Comparison of Apparatus, Sample, and Procedure - English 18

	T 99	T 180
Mold Volume, ft^3	Methods A, C: 1/30	Methods A, C: 1/30
	Methods B, D: 1/13.33	Methods B, D: 1/13.33
Mold Diameter, in.	Methods A, C: 4.000	Methods A, C: 4.000
	Methods B, D: 6.000	Methods B, D: 6.000
Mold Height, in.	4.584	4.584
Detachable Collar Height, in.	2	2
Rammer Diameter, in.	2.000	2.000
Rammer Mass, lb	5.5	10
Rammer Drop, in.	12	18
Layers	3	5
Blows per Layer	Methods A, C: 25	Methods A, C: 25
	Methods B, D: 56	Methods B, D: 56
Material Size, in.	Methods A, B: No. 4 minus	Methods A, B: No. 4 minus
	Methods C, D: 3/4 minus	Methods C, D: 3/4 minus
Test Sample Size, lb	Method A: 7 Method B: 16 Method C: 12(1) Method D: 25(1)	
Energy, lb-ft/ ft^3	12,375	56,250

(1)This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

Breaking up sample

19

Sample

If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 140°F. Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.

Sieve Mold	– No. 4	– 3/4 in.
4-inch	A	C
6-inch	B	D

Obtain a representative test sample of the mass required by the agency by passing the material through the sieve required by the agency. See Table 1 or Table 2 for test sample mass and material size requirements. 20

Note 1: Both T 99 & T 180 have four methods (A, B, C, D) that require different masses and employ different sieves.

21 ***Note 2:*** If the sample is plastic (clay types), it should stand for a minimum of 12 hours after the addition of water to allow the moisture to be absorbed. In this case, several samples at different moisture contents should be prepared, put in sealed containers and tested the next day. Instances where the material is prone to degradation i.e. granular material a compaction sample with differing moisture content should be prepared for each point.

22

Procedure

1. Determine the mass of the clean, dry mold. Include the base plate, but exclude the extension collar. Record the mass to the nearest 0.005 kg (0.01 lb).

23

2. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 to 6 percentage points below optimum moisture content. See note 2.

3. Form a specimen by compacting the prepared soil in the mold (with collar attached) in

Typical mold

approximately equal layers. For each layer, spread the loose material uniformly in the mold. Lightly tamp the fluffy material with the manual rammer or other similar device. This establishes a firm surface on which to hold the rammer sleeve. Compact each layer with uniformly distributed blows from the rammer. See Table 2 for mold size, number of layers, number of blows, and rammer specification for the various test methods. Use the method specified by the agency. If material that has not been compacted remains adjacent to the walls of the mold and extends above the compacted surface, trim it down.

Note 3: During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process.

24 4. Remove the extension collar. Avoid shearing
25 off the sample below the top of the mold. A
rule of thumb is that the material compacted in
the mold should not be over 1/4 in. above the
top of the mold once the collar has been
removed.

5. Trim the compacted soil even with the top of
the mold with the beveled edge of the
26 straightedge.

27 6. Determine the mass of the mold and wet soil in kg to the nearest 0.005 kg (0.01 lb) or better.

7. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 6.

8. Calculate the wet density as indicated below under "Calculations."

28 9. Extrude the material from the mold. For soils
29 and soil aggregate mixtures slice vertically
30 through the center and take a representative
moisture content sample from one of the cut faces insuring that all layers are represented. For granular materials a vertical face will not exist. Take a representative sample. This sample must meet the sample size requirements of the test method to be used to determine moisture content.

Moisture sample

Note 4: When developing a curve for free-draining soils, such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

31

10. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255/T 265.

32

11. Thoroughly break up the remaining portion of the molded specimen until it will again pass through the sieve, as judged by eye, and add to the remaining portion of the sample being tested. See note 2.

12. Add sufficient water to increase the moisture content of the remaining soil by approximately 1 to 2 percentage points and repeat the above procedure.

13. Continue determinations until there is either a decrease or no change in the wet density. A minimum of five determinations is usually necessary.

Calculations

1. Calculate the wet density, in lb/ft^3, by multiplying the wet mass from Step 7 by the appropriate factor chosen from the two below. 33

Method A & C molds: 30)
Method B & D molds: 13.33)

Note 5: The moist mass is in kg (lb). The factors are the inverses of the mold volumes in ft^3 shown in Table 2.

1/(1/30) = 30
1/(1/13.33) = 13.33 34

Example – Method A or C mold:

Wet mass = 4.22 lb

(4.22)(30) = 126.6 lb/ft^3 Wet Density

2. Calculate the dry density as follows. 35

$$\rho_d = \left(\frac{\rho_w}{w + 100}\right) \times 100 \quad \text{or} \quad \rho_d = \left(\frac{\rho_w}{\frac{w}{100} + 1}\right)$$

where

ρ_d = Dry density, lb/ft^3

ρ_w = Wet density, lb/ft^3

w = Moisture content, as a percentage

Example: 36

ρ_w = 126.6 lb/ft^3 and w = 14.7%

$$\rho_d = \left(\frac{126.6\,lb/\text{ft}^3}{14.7 + 100}\right) \times 100 = 110.4\ lb/\text{ft}^3$$

or

$$\rho_d = \left(\frac{126.6\,lb/\text{ft}^3}{(14.7/100) + 1}\right) = 110.4\ lb/\text{ft}^3$$

Moisture-Density Curve Development

When dry density is plotted on the vertical axis versus moisture content on the horizontal axis, and the points are connected, a moisture-density curve is developed. The peak of the curve has, as coordinates, the maximum dry density, or just “maximum density,” and the “optimum moisture content” of the soil. 37

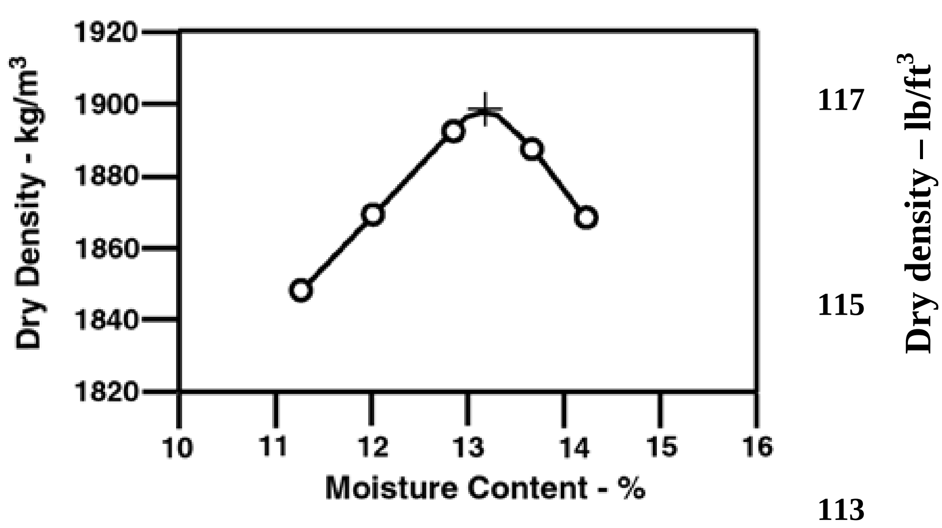
Example:

Given the following dry density and corresponding moisture content values, develop a moisture-density relations curve and determine maximum dry density and optimum moisture content.

Dry Density, lb/ft^3	Moisture Content, %
114.3	11.3
115.7	12.1
116.9	12.8
116.7	13.6
115.9	14.2

38

39



Ideally, there will be three points on the dry side of the curve and two points on the wet side. In this case, the curve has its peak at:

Maximum dry density = 117.0 lb/ft^3

Optimum water content = 13.2%

Note that both values are approximate, being based on sketching the curve to fit the points.

40

Report

Results shall be reported on standard forms approved by the agency. Report maximum dry density to the closest 0.1 lb/ft^3 and optimum moisture content to the closest 0.1 percent.

41

Tips!

- Ideally, obtain dry 3 points and 2 wet points. This produces a reliable moisture-density curve.
- Moisture-density curves are based on dry, densities.
- If oversize material exists, corrections must be made

.

REVIEW QUESTIONS

1. Describe how the plotted data is used to determine optimum moisture content and maximum dry density.

2. How many blows of the rammer are required per lift for the various procedures and methods?

3. Describe how the sample for moisture content is obtained.

4. What sample mass is required for Method A of the T 99 test?

   For Method C of the T 180 test?

PERFORMANCE EXAM CHECKLIST

MOISTURE-DENSITY RELATION OF SOILS
FOP FOR AASHTO T 99 and AASHTO T 180

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
Procedure		
1. If damp, sample dried in air or drying apparatus, not exceeding 140°F?	_____	_____
2. Sample pulverized and adequate amount sieved over the appropriate sieve No. 4 or ¾ in. to determine oversize (coarse particle) percentage?	_____	_____
3. Sample passing the sieve has appropriate mass?	_____	_____
4. Sample mixed with water to 4 to 6 percent below expected optimum moisture content?	_____	_____
5. Layer of soil placed in mold with collar attached?	_____	_____
6. Mold placed on rigid and stable foundation?	_____	_____
7. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
8. Soil placed in appropriate number of approximately equal layers (3 or 5)?		
9. Collar removed without shearing off sample?	_____	_____
10. Approximately 1/4 in. of compacted material above the top of the base of the mold?	_____	_____
11. Soil trimmed to top of mold with the beveled edge of the straightedge?	_____	_____
12. Mass of mold and contents determined to appropriate precision?	_____	_____
13. Wet mass of specimen multiplied by appropriate factor to obtain wet density 30, 13.33?	_____	_____
14. Soil removed from mold using a sample extruder if needed?	_____	_____
15. Soil sliced vertically through center?	_____	_____
16. Moisture sample removed from one cut face insuring all layers are represented?	_____	_____
17. Moist mass determined immediately to 0.1 g?	_____	_____

OVER

Procedure Element	**Trial 1**	**Trial 2**
18. Moisture sample mass of correct size?	_____	_____
19. Sample dried and water content determined according to T 255/T 265?	_____	_____
20. Remainder of material from mold broken up to about passing sieve size and added to remainder of original test sample?	_____	_____
21. Water added to increase moisture content of the remaining sample in 1 to 2 percent increments?	_____	_____
22. Steps 2 through 15 repeated for each increment of water added?	_____	_____
23. If soil is plastic (clay types):		
a. Samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content?	_____	_____
b. Samples placed in covered containers and allowed to stand for at least 12 hours?	_____	_____
24. If material is degradable:		
Multiple samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content?	_____	_____
25. Process continued until wet density either decreases or stabilizes?	_____	_____
26. Moisture content and dry density calculated for each sample?	_____	_____
27. Dry density plotted on vertical axis, moisture content plotted on horizontal axis, and points connected with a smooth curve?	_____	_____
28. Moisture content at peak of curve recorded as optimum water content and recorded to nearest 0.1 percent?	_____	_____
29. Dry density at optimum moisture content reported as maximum density, to nearest 0.1 lb/ft^3?	_____	_____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

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Examiner Signature ________________________________WAQTC #:_______________

FAMILY OF CURVES – ONE-POINT METHOD
FOP FOR AASHTO T 272

01

Significance

02 Soils sampled from one source will have many different moisture-density curves, but if a group of these curves is plotted together, similarities or relationships are usually seen. A family of curves is a group of soil moisture-density relationships that reveal similarities characteristic of the soil type and source. Higher density soils have curves with steeper slopes and maximum dry densities at lower optimum moisture contents, while the lower density soils have flatter curves with higher optimum moisture contents. Figure 1 is an example of such a curve, and was taken from AASHTO T 272.

03 In the field, density and moisture content are determined, and a single point is plotted on the family of curves. If the point plots on a curve, that curve may be used to represent the moisture-density relation for the soil. If the point plots between two curves, a new curve is sketched between the existing curves and the new curve is used.

Scope

04 This procedure provides for a rapid determination of the maximum density and optimum moisture content of a soil sample utilizing a family of curves and a one-point determination in accordance with AASHTO T 272. This procedure is related to FOP for AASHTO T 99/T 180.

One-point determinations are made by compacting the soil in a mold of a given size with a specified rammer dropped from a specified height. Four alternate methods – A, B, C, D – are used and correspond to the methods described in FOP for AASHTO T 99/T 180. The method used in AASHTO T 272 must match the method used in FOP for AASHTO T 99/T 180.

Apparatus

See the FOP for AASHTO T 99/T 180.

Sample

Sample size determined according to the FOP for AASHTO T 310. In cases where the existing family can not be used a completely new curve will need to be developed and the sample size will be determined by the FOP for AASHTO T 99/T 180.

Procedure

See the FOP for AASHTO T 99/T 180.

Calculations

See the FOP for AASHTO T 99/T 180.

Maximum Dry Density and Optimum Moisture Content Determination

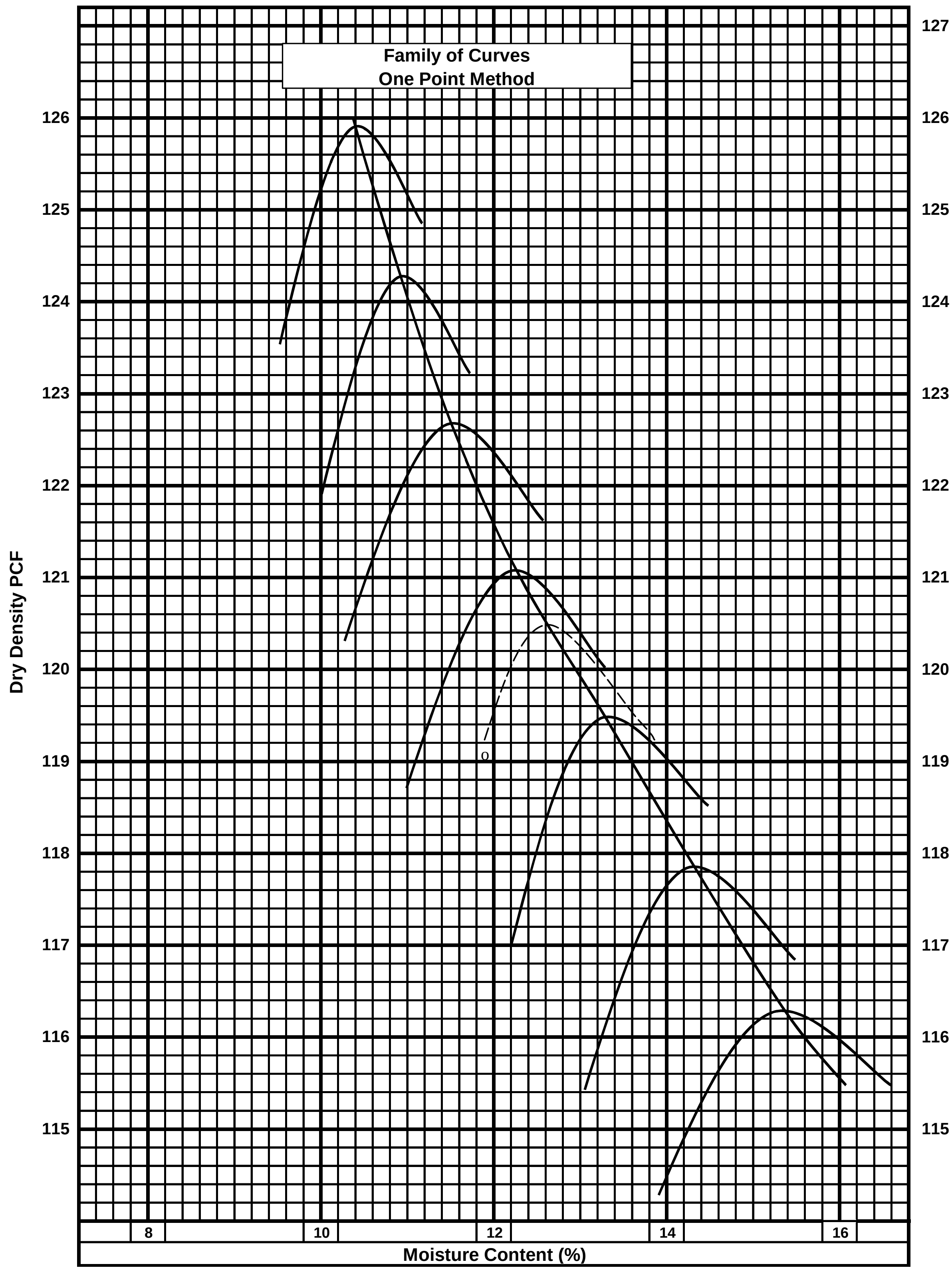
1. If the moisture-density one-point falls on one of the curves in the family of curves, the maximum
05 dry density and optimum moisture content defined by that curve shall be used.

2. If the moisture-density one-point falls within the family of curves but not on an existing curve, a new curve shall be drawn through the plotted single point parallel and in character with the nearest existing curve in the family of curves. The maximum dry density and optimum moisture content as defined by the new curve shall be used.

Note 1: If the one-point plotted within or on the family of
06 curves does not fall in the 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one-point within this range.

3. If the family of curves is such that the new curve through a one-point is not well defined or is in any way questionable, a full moisture-density relationship shall be made for the soil to correctly define the new curve and verify the applicability of the family of curves.

Note 2: New curves drawn through plotted single point
07 determinations shall not become a permanent part of the family of curves until verified by a full moisture-density procedure following the FOP for AASHTO T 99/T 180.


Family of Curves
One Point Method
Dry Density PCF
127
126
125
124
123
122
121
120
119
118
117
116
115
8
10
12
14
16
Moisture Content (%)
o

Example:

A moisture-density procedure (AASHTO T 99 or AASHTO T 180) was run. A dry density of 119.1 lb/ft^3 at 11.9 percent moisture were determined. This point was plotted on the appropriate family between two previously developed curves.

The "dashed" curve beginning at the moisture-density one-point was sketched between the two existing curves. A maximum dry density of 120.4 lb/ft^3 and optimum moisture of 12.7 percent were estimated.

10 **Report**

Results shall be reported on standard forms approved by the agency. Report maximum dry density to the closest 0.1 lb/ft^3 and optimum moisture content to the closest 0.1 percent.

11 **Tips!**

- Make sure that the moisture content of the one-point sample is between 80 and 100 percent of optimum.
- Remember that a full moisture-density procedure shall be made if the curve drawn through the one-point is not well defined or is questionable.

REVIEW QUESTIONS

1. With what other procedure(s) is this procedure related?

2. How are the two procedures used together?

3. Describe the limitations of using the one-point determination with a family of curves?

PERFORMANCE EXAM CHECKLIST

FAMILY OF CURVES - ONE-POINT METHOD
FOP FOR AASHTO T 272

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. One-point determination of dry density and corresponding moisture content made in accordance with the FOP for AASHTO T 99/T 180?	_____	_____
a. Correct size No.4 or 3/4 in. material used?	_____	_____
b. Correct number of blows per layer used (25 or 56)?	_____	_____
c. Correct number of layers used (3 or 5)?	_____	_____
d. Moisture content determined in accordance with FOP for AASHTO T 255/T 265 (if allowed T 217)?	_____	_____
2. One-point plotted on family of curves supplied?	_____	_____
3. One-point falls within 80 to 100 percent of optimum moisture content in order to be valid?	_____	_____
4. If one-point does not fall within 80 to 100 percent of optimum moisture content, another one-point determination with an adjusted water content is made?	_____	_____
5. Maximum dry density and corresponding optimum moisture content correctly estimated?	_____	_____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

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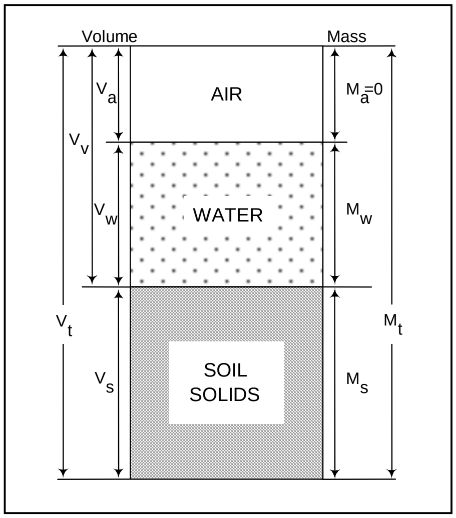
Examiner Signature ______________________________ WAQTC #:______________

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE FOP FOR AASHTO T 85



Phase diagram

01 ## Significance

Bulk specific gravity is a characteristic used for calculating the volume occupied by the aggregate or various mixtures containing aggregate, including
02 portland cement concrete, bituminous mixes, and other materials that are proportioned or analyzed on an absolute volume basis. Specific gravity is the ratio of the mass of a material to the mass of an
03 equal volume of water. Several categories of specific gravity are used relative to aggregate.

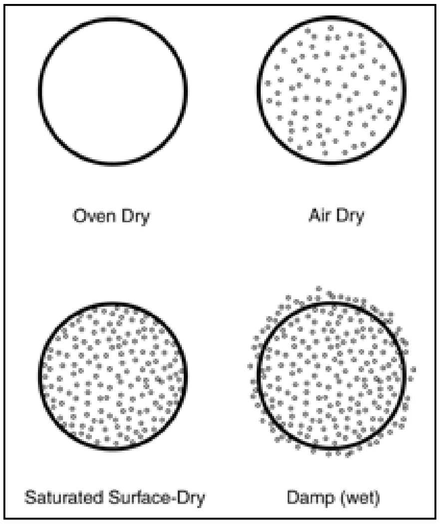
Bulk specific gravity (oven-dry), G_{sb}(OD), is used for computations when the aggregate is dry. Bulk
04 specific gravity (saturated surface dry, or SSD), G_{sb}(SSD), is used if the aggregate is wet. Apparent specific gravity, G_{sa}, is based solely on the solid material making up the constituent particles and does not include the pore space within the particles that is accessible to water.

Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates, when used, may contain an amount of absorbed moisture less than the 15 hours soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content.

The pores in lightweight aggregates may or may not become filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without satisfying most of the aggregates' absorption potential. Therefore, this method is not intended for use with lightweight aggregate.

Scope

This procedure covers the determination of specific gravity and absorption of coarse aggregate in accordance with AASHTO T 85. Specific gravity may be expressed as bulk specific gravity G_{sb}(OD),
05 bulk specific gravity, saturated surface dry G_{sb}(SSD), or apparent specific gravity (G_{sa}). G_{sb} and absorption are based on aggregate after 15 hours soaking in water. This procedure is not intended to be used with lightweight aggregates.



Moisture conditions

Terminology

06 Absorption – the increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 230 ±9°F for sufficient time to remove all uncombined water.

Saturated surface dry (SSD) – condition of an aggregate particle when the permeable voids are filled with water, but no water is present on exposed surfaces.

Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

Apparent Specific Gravity (G_{sa}) – the ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity G_{sb}(OD) – the ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity (SSD) G_{sb}(SSD) – the ratio of the mass, in air, of a volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours (but not including the voids between particles), to the mass of an equal volume of gas-free distilled water at a stated temperature.

07

Definition: (Specific Gravity Symbols)

“G” Denotes that **this is a Specific Gravity**

G_{sb}

Denotes **Type of Specific Gravity**

b = bulk
a = apparent
m = maximum
e = effective

Denotes **Type of Material**

s = soil or “stone”
b = binder
m = mix

Sample container and scale

08

09

Apparatus

- Balance or scale with a capacity of 5 kg, sensitive to 1 g. Meeting the requirements of AASHTO M 231.
- Sample container, wire basket of No. 6 or smaller mesh, with a capacity of 1 to 2 gal to contain aggregate with a nominal maximum size of 1½ in. or smaller; larger basket for larger aggregates.
- Water tank, watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water level constant.

- Suspension apparatus: wire used to suspend apparatus shall be of smallest practical diameter.
- Sieves No. 4, or other sizes as needed, conforming to AASHTO M 92.
- Large absorbent towel

Sample Preparation

1. Obtain the sample in accordance with the FOP for AASHTO T 2 (see Note 1).

10

2. Mix the sample thoroughly and reduce it in accordance with the FOP for AASHTO T 248.
3. Reject all material passing the appropriate sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. The minimum mass is given in Table 1.

Note 1: If this procedure is used only to determine the G_{sb} of oversized material for the FOP for AASHTO T 99 or T 180 and in the calculations for the FOP for AASHTO T 224. The material can be rejected over the appropriate sieve, T 99 / T 180 methods A & B No.4, T 99 / T 180 methods C & D the 3/4 in.

Table 1

11

Nominal Maximum Size*, (in.)	Minimum Mass of Test Sample, g (lb)
1/2 or less	2000 (4.4)
3/4	3000 (6.6)
1	4000 (8.8)
1½	5000 (11)
2	8000 (18)
2½	12,000 (26)
3	18,000 (40)

* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

Procedure

1. Dry the test sample to constant mass at a temperature of 230 ±9°F and cool in air at room temperature for 1 to 3 hours.

Note 2: Where the absorption and specific gravity values are
12 to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-hour soaking may also be eliminated.

2. Immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

Note 3: When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and then combine values obtained.

3. Place the empty basket into the water bath and attach to the balance. Inspect the immersion tank to insure the water level is at the overflow outlet height. Tare the balance with the empty basket attached in the water bath.

4. Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually.

Note 4: A moving stream of air may be used to assist in the drying operation, but take care to avoid evaporation of water from aggregate pores.

13

14

Submerged container

5. Determine the SSD mass of the sample, and record this and all subsequent masses to the nearest 0.1 g or 0.1 percent of the sample mass, whichever is greater. Designate this mass as "B".
6. Re-inspect the immersion tank to insure the water level is at the overflow outlet height. Immediately place the SSD test sample in the sample container and weigh it in water maintained at 73.4 ±3°F. Shake the container to release entrapped air before recording the weight. Designate this submerged weight as "C".

Note 5: The container should be immersed to a depth sufficient to cover it and the test sample during mass determination. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

7. Remove the sample from the basket. Ensure all material has been removed and place in a container of known mass.
8. Dry the test sample to constant mass in accordance with the FOP for AASHTO T 255/T 265 (Aggregate section) and cool in air at room temperature for 1 to 3 hours. Designate this mass as "A".

Calculations

Perform calculations and determine values using the appropriate formula below. In these formulas, A = oven dry mass, B = SSD mass, and C = weight in water.

Bulk specific gravity – G_{sb}(OD) 15

$G_{sb}(OD) = A / (B-C)$

Bulk specific gravity, SSD (G_{sb} SSD) 16

$G_{sb}(SSD) = B / (B - C)$

Apparent specific gravity (G_{sa}) 17

$G_{sa} = A / (A - C)$

Absorption 18

Absorption = $[(B - A) / A] \times 100$

Sample Calculations

Sample	A	B	C	B - C	A - C	B - A
1	2030.9	2044.9	1304.3	740.6	726.6	14.0
2	1820.0	1832.5	1168.1	664.4	651.9	12.5
3	2035.2	2049.4	1303.9	745.5	731.3	14.2

Sample	G_{sb}(OD)	G_{sb}(SSD)	G_{sa}	Absorption	Reported
1	2.742	2.761	2.795	0.689	0.7
2	2.739	2.758	2.792	0.687	0.7
3	2.730	2.749	2.783	0.698	0.7
Average	2.737	2.756	2.790	0.691	0.7

These calculations demonstrate the relationship between G_{sb}(OD), G_{sb} SSD, and G_{sa}. G_{sb}(OD) is always lowest, since the volume includes voids permeable to water. G_{sb}(SSD) is always intermediate. G_{sa} is always highest, since the volume does not include voids permeable to water. When running this test, check to make sure the values calculated make sense in relation to one another.

19 **Report**

Results shall be reported on standard forms approved by the agency. Report specific gravity values to 3 decimal places and absorption to 0.1 percent.

20

Tips!

- Shake the container and sample when weighing in water to release entrapped air.
- Compare G_{sb}(OD), G_{sb}(SSD), and G_{sa} to see if they make sense.

REVIEW QUESTIONS

1. What size sample is required for aggregate with a nominal maximum size of 1 in.?

2. When is soaking required? For how long must material be soaked?

3. When, in the process, are dry and SSD masses determined?

PERFORMANCE EXAM CHECKLIST

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE FOP FOR AASHTO T 85

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Sample obtained by FOP for AASHTO T 2 and reduced by FOP for AASHTO T 248 or from FOP for AASHTO T 99 / T 180?	_____	_____
2. Screened on the appropriate size sieve?	_____	_____
3. Sample mass appropriate?	_____	_____
4. Particle surfaces clean?	_____	_____
5. Dried to constant mass 230 ±9°F and cooled to room temperature?	_____	_____
6. Covered with water for 15 to 19 hours?	_____	_____
7. Basket placed into immersion tank and attached to balance?	_____	_____
8. Immersion tank inspected for proper water height?	_____	_____
9. Balance tared with basket in tank and temperature checked 73.4 ±3°F?	_____	_____
10. Sample removed from water and rolled in cloth to remove visible films of water?	_____	_____
11. Larger particles wiped individually?	_____	_____
12. Evaporation avoided?	_____	_____
13. Sample mass determined to 0.1 g?	_____	_____
14. Sample immediately placed in basket, in immersion tank?	_____	_____
15. Entrapped air removed before weighing by shaking basket while immersed?	_____	_____
16. Immersed sample weight determined to 0.1 g?	_____	_____
17. All the sample removed from basket?	_____	_____
18. Sample dried to constant mass and cooled to room temperature?	_____	_____

OVER

Procedure Element	**Trial 1**	**Trial 2**
19. Sample mass determined to 0.1 g?	______	______
20. Proper formulas used in calculations?	______	______

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

____
____
____
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Examiner Signature _________________________________WAQTC #:________________

CORRECTION FOR COARSE PARTICLES IN THE SOIL COMPACTION TEST FOP FOR AASHTO T 224

01 Significance

The procedures used to determine moisture-density relations in soils and soil-aggregate mixtures (AASHTO T 99 or T 180) are performed on samples obtained by sieving material through specified sieves. AASHTO T 99 and T 180 use the No. 4 or 3/4 in. sieve depending on the method A, B, C, or D. These size limits are used because the equipment cannot accommodate large material.

When the material contains oversized particles, an adjustment must be made in the maximum dry density. Two methods are available for correction; lab to field or field to lab. This FOP will cover
02 only lab to field corrections (see AASHTO T 224-00 for field to lab corrections).

03

Scope

This procedure covers the adjustment of the maximum dry density determined by FOP for AASHTO T 99/ T 180 to compensate for coarse particles retained on the No. 4 or 3/4 in. sieve. For Methods A and B of FOP for AASHTO T 99/ T 180 the adjustment is based on the percent, by mass, of material retained on the No. 4 sieve and the bulk specific gravity, G_{sb}(OD) of the material retained on the No. 4 sieve. A maximum of 40% of the material can be retained on the No. 4 sieve for this method to be used. For Methods C and D of FOP for AASHTO T 99/ T 180, the adjustment is based on the percent, by mass, of material retained on the 3/4 in. sieve and the G_{sb}(OD) of the material retained on the 3/4 in. sieve. A maximum of 30% of the material can be retained on the 3/4 in. sieve for this method to be used. Whether the split is on the No. 4 or the 3/4 in. sieve all material retained on that sieve is defined as oversized material.

This method applies to soils with percentages up to the maximums listed above for oversize particles. A correction may not be practical for soils with only a small percentage of oversize material.

Agency shall specify a minimum percentage below which the method is not needed. If not specified, this method applies when more than 5 percent by weight of oversize particles is present.

Adjustment Equation for Moisture

Along with density the moisture content can be corrected. The moisture content can be determined by the FOP for AASHTO T 255 / T 265, FOP for
04 AASHTO T 217 or the Nuclear density gauge moisture content reading from the FOP for AASHTO T 310. If the nuclear gauge moisture reading is used or when the moisture content is determined on the entire sample (both fine and oversized particles) the use of the adjustment equation is not needed. Combined moisture contents with material having an appreciable amount of silt or clay should be performed using the FOP for AASHTO T 255 / T 265 (Soil). Moisture contents used from FOP for AASHTO T 310 must meet the criteria for that method.

When samples are split for moisture content (oversized and fine materials) the following adjustment equations must be followed.

1. Split the sample into oversized material and fine material.
2. Dry the oversized material following the FOP for AASHTO T 255 / T 265 (Aggregate). If the fine material is sandy in nature, dry using the FOP for AASHTO T 255 / T 265 (Aggregate). If the fine material has any
05 appreciable amount of clay, dry using the FOP for AASHTO T 255 / T 265 (Soil).

3. Calculate the dry mass of the oversize and fine material as follows.

$$M_D = \frac{M_m}{(1+MC)}$$

06 Where:

M_D = mass of dry material (fine or oversize particles).

M_m = mass of moist material (fine or oversize particles).

MC = moisture content of respective fine or oversized, expressed as a decimal.

4. Calculate the percentage of the fine and oversized particles by dry weight of the total sample as follows: See note 2.

$$P_f = \frac{100\,M_{DF}}{(M_{DF}+M_{DC})}$$

$$73.0\% = \frac{(100)\,(15.4\text{ lbs})}{(15.4 + 5.7\text{ lbs})}$$

And

$$P_c = \frac{100\,M_{DC}}{(M_{DF}+M_{DC})}$$

$$27.0\% = \frac{(100)\,(5.7\text{lbs})}{(15.4 + 5.7\text{lbs})}$$

Or for P_c $P_c = 100 - P_f$

Where:

P_f = percent of fine particles, of sieve used, by weight.

P_C = percent of oversize particles, of sieve used, by weight.

M_{DF} = mass of fine particles.

M_{DC} = mass of oversize particles.

5. Calculate the corrected moisture content as follows:

07

$$MC_T = \frac{[(MC_F)(P_f) + (MC_c)(P_c)]}{100}$$

MC_T = corrected moisture content of combined fines and oversized particles, expressed as a % moisture.

MC_F = moisture content of fine particles, expressed as a % moisture.

MC_C = moisture content of oversized particles, expressed as a % moisture.

$$MC_T = \frac{[(10.6)(73) + (2.1)(27)]}{100}$$

Note 1: Moisture content of oversize material can be assumed to be two (2) percent for most construction applications.

Note 2: In some field applications agencies will allow the percentages of oversize and fine materials to be determined with the materials in the wet state.

Adjustment Equation Density

6. Calculate the corrected dry density of the total sample (combined fine and oversized particles) as follows:

$$D_d = \frac{100\, D_f k}{[(D_f)(P_c) + (k)(P_f)]}$$

or

$$D_d = \frac{100}{\frac{P_f}{D_f} + \frac{P_c}{k}}$$

Where:

08 D_d = corrected total dry density (combined fine and oversized particles) lb/ft^3.

D_f = dry density of the fine particles determined in the lab lb/ft^3

P_C = percent of oversize particles, of sieve used, by weight

P_f = percent of fine particles, of sieve used, by weight

k = 62.4 * G_{sb} (oven dry basis) of coarse particles (lb/ft^3).

Note 3: If the G_{sb} is known, then this value will be used in the calculation. For most construction activities the G_{sb}(OD)of aggregate may be assumed to be 2.600.

Calculation

Sample Calculations:

Maximum laboratory dry density (D_F):	140.4 lb/ft^3 11
Percent coarse particles (P_C):	27%
Percent fine particles (Pf):	73%
Mass per volume of coarse particles (k):	(2.697) (62.4) = 168.3 lb/ft^3

$$D_d = \frac{(100)\,(140.4\,\text{lb/ft}^3)(168.3\,\text{lb/ft}^3)}{[(140.4\,\text{lb/ft}^3)\,(27) + (168.3\,lb/ft^3)(73)]}$$

$$D_d = \frac{2{,}362{,}932}{[3790.8 + 12285.9]}$$

$$D_d = \frac{2{,}362{,}932}{16{,}076.7}$$

D_d = 146.98 say 147.0 lb/ft^3

12 ## Report

Results shall be reported on standard forms
13 approved by the agency. Report adjusted maximum dry density to the closest 0.1 lb/ft^3.

Tips!

14 • Base the adjustment on the percent retained on the sieve size specified in the FOP for AASHTO T 99 / T 180.

REVIEW QUESTIONS

1. Describe the purpose of this procedure.

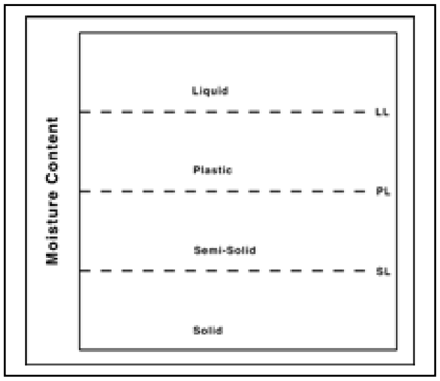
2. The adjustment is based on the mass of material retained on what size sieve?

3. A soil-aggregate mixture has a maximum dry density of 138.6 lb/ft^3. The coarse particles make up 22 percent of the material, and have a G_{sb}(OD) of 2.631.

   What is the corrected maximum density?

DETERMINING THE LIQUID LIMIT OF SOILS FOP FOR AASHTO T 89

Significance



Material phase and moisture content

01 Fine-grained soils, particularly clays, exhibit
different properties at different moisture contents.
At very low moisture contents, the material acts like
02 a solid. As the moisture content rises, the material
moves from solid to semi-solid to plastic to liquid
form.

03 The moisture content at the boundary between
semi-solid and plastic states is known as the plastic
limit (PL). The moisture content at the boundary
between the plastic and liquid states is known as the
liquid limit (LL). The difference between the
04 plastic and liquid limits is called the plasticity index
(PI), and indicates the size of the range over which
the material acts as a plastic – capable of being
deformed under stress, but maintaining its form
when unstressed.

Fine-grained soils also exhibit shrinking and swelling as the moisture content changes. As water content increases from dry to wet, no change in volume occurs below a certain moisture content, known as the shrinkage limit (SL). Above the SL, volume increases as moisture content increases.

For these reasons, knowledge of the LL, PL, and PI, and sometimes the SL, are important to quality assurance in roadway construction.

Scope

This procedure covers the determination of the liquid limit of a soil in accordance with AASHTO T 89. It is used in conjunction with the FOP for AASHTO T 90, Determining the Plastic Limit and Plasticity Index of Soils. The three values are used for soil classification and other purposes.

Liquid limit apparatus

05

Apparatus

06
- Dish: preferably unglazed porcelain or similar mixing dish, of approximately 4.5 inch diameter.
- Spatula: having a blade 3 to 4 in. long and about 3/4 in. wide.
- Liquid Limit Device: manually or mechanically operated, consisting of a brass cup, carriage, and base plate.
- Grooving Tool: used to cut the soil in the liquid limit device cup.
- Gauge: part of the grooving tool or a separate metal bar, 10.0 ±0.2 mm (0.394 ±0.008 in). thick and approximately 50 mm (2 in.) long.
- Containers: corrosion resistant, suitable for repeated heating and cooling, having close fitting lids to prevent the loss of moisture. One container is needed for each moisture content determination.
- Balance: conforming to AASHTO M 231, class G1, sensitive to 0.01 g with a 1200 g capacity.
- Oven: thermostatically controlled, capable of maintaining temperatures of 230 ±9°F.
- Graduated cylinders for measuring distilled or demineralized water.

- Pulverizing Apparatus**:** Either mortar and rubber-covered pestle or any device suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains of soil.
- Sieves: A series of the following sizes: ¼ in., #4, #10, #40 and a pan.

Adjustment of Liquid Limit Device

The liquid limit device shall be inspected to
07 determine that the device is in good working order; that the pin connecting the cup is not worn to permit side play; that the screws connecting the cup to the hanger are tight; that the points of contact on the cup and base are not excessively worn; that the lip of the cup is not excessively worn; and that a groove has not been worn in the cup. The grooving tool shall be inspected to determine that the critical dimensions are correct.

Note 1: Wear is considered excessive when the point of contact on the cup or base exceeds approximately 0.5 in. in diameter, or when any point on the rim of the cup is worn to approximately 1/2 the original thickness. A slight groove in the center of the cup is not objectionable. If the groove becomes pronounced, the cup shall be replaced. A base that is excessively worn may be refinished as long as it is maintained within the tolerances specified.

Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10.0 ±0.2 mm (0.394 ±0.008 in).

Note 2: Check the height of the drop, before each new sample, by turning the crank at two revolutions per second while holding the gauge in position against the cup. If a ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from gauge, readjust the height of the drop. If the cup rocks on the gauge during this checking operation, the cam follower pivot is excessively worn and should be replaced.

Sample

Sample Preparation

08 Samples must be prepared per AASHTO T 87 or T 146. Obtain a sample with a mass of about 100 g taken from the portion of the material passing the
09 No. 40 sieve.

The mass required depends upon the method chosen. Method A (multi-point method) requires approximately 100 g. Method B (single point method) requires approximately 50 g.

Procedure – Method A (Multi-Point)

Spreading soil

10 1. Place the sample in the dish and thoroughly mix with 15 to 20 mL of distilled or demineralized water by alternately and repeatedly stirring, kneading, and chopping with a spatula. Further additions of water shall be in increments of 1 to 3 mL. Each increment shall be thoroughly mixed with the soil before another increment is added. Once testing has begun, no additional dry soil should be added to the moistened soil. The cup of the Liquid Limit device shall not be used for mixing soil and water. If too much water is added, the sample shall either be discarded or mixed and kneaded until natural evaporation lowers the moisture content.

Note 3: Some soils are slow to absorb water. It is possible to add water so fast that a false LL value is obtained. This can be avoided by allowing more mixing and/or time. Also, tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water.

11 2. Add sufficient water to form a uniform mass of a stiff consistency.

3. Place enough material in the cup so that, when squeezed and spread with the spatula, the soil will rest in the cup above the spot where the cup rests on the base and will be 10 mm thick at the point of maximum thickness. Use as few strokes of the spatula as possible, taking care to prevent the entrapment of air bubbles in the sample.

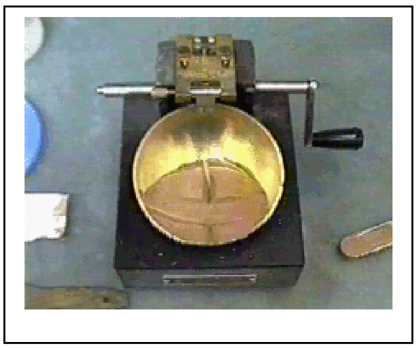
Liquid limit procedure

12 4. Divide the soil in the cup with a firm stroke of the grooving tool. Avoid tearing of the sides of the groove or slipping of the soil cake on the cup. Up to six strokes are permitted. The depth

of the groove should be increased with each stroke, and only the last stroke should scrape the bottom of the cup.

5. Lift and drop the cup by turning the crank at a rate of approximately two revolutions per second until the two halves of the soil pat come together along a distance of about 0.5 in. Do not hold the base while the crank is turned. Record the number of shocks required to close
13 the groove.

Note 4: Some soils tend to slide on the cup instead of flowing. If this occurs, water should be added, the sample remixed, and the procedure repeated. If the soil continues to slide on the cup, the test is not applicable and a note should be made that the liquid limit could not be determined.



Sampling for moisture

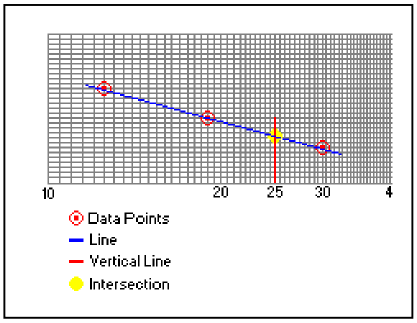
6. Obtain a moisture content sample by slicing
14 through the soil pat perpendicularly with the spatula and through the center of the groove. Place it into a suitable container for subsequent
15 moisture determination.

7. Determine the moisture content of the moisture
16 content sample in accordance with the FOP for AASHTO T 255/T 265 (Soil).

8. Place the soil remaining in the cup back in the mixing dish and add 1 to 3 mL of water, or use previously prepared portions to which sufficient water has been added to result in a more fluid condition.

9. Repeat Steps 3 through 8, a minimum of two
17 times. The object is to have a determination in all three shock ranges 25-35, 20-30, & 15-25.

Flow Curve – Method A



Liquid limit flow curve

18 Prepare a flow curve on a semi-logarithmic graph with moisture content on the arithmetic vertical axis and the number of shocks on the logarithmic
19 horizontal axis. The flow curve is a straight line drawn as closely as possible through three or more plotted points.

Liquid Limit – Method A

20 Determine the liquid limit. The moisture content at the intersection of the flow curve and the 25 shock line is the liquid limit.

Procedure – Method B (Single-Point)

21
1. Place the sample in the dish and thoroughly mix with 8 to 10 mL of distilled or demineralized water, and following the mixing procedure in Method A, Step 1.
2. Follow the procedure in Method A except that the soil pat should be prepared with water to produce a consistency that will close the two halves of the soil pat at least 0.5 in. within 22 to 28 shocks of the cup.

Note 5: Groove closures occurring between 15 and 40 blows may be accepted if variations of ±5 percent of the true liquid limit are tolerable.

22
3. Return the soil remaining in the cup to the mixing dish and, without adding any additional water, repeat Step 2. If the closure again occurs within the acceptable range, obtain a moisture content specimen.
4. Determine the moisture content of the moisture content sample in accordance with the FOP for AASHTO T 255/T 265 (Soil).

Liquid Limit – Method B

Calculate the liquid limit as follows:

$$LL = (w_N)(N/25)^{0.121}$$

23

N	$(N/25)^{0.121}$	N	$(N/25)^{0.121}$
22	0.985	26	1.005
23	0.990	27	1.009
24	0.995	28	1.014
25	1.000		

$$LL = (w_N)(N/25)^{0.121}$$

Where:

LL = liquid limit

w_N = moisture content of sample at N blows

N = number of blows

Example:

w_N = 16.0 % and N = 23

$LL = (16.0)(23/25)^{0.121} = 15.8$, say 16%

24

Report

Results shall be reported on standard forms approved by the agency. Report LL to the nearest whole percent.

25

Tips!

- Do <u>not</u> mix dry soil with moist soil in order to reduce moisture content.
- Be careful with grooving tool. Use up to six strokes to carefully separate the sample, rather than forcing the sample apart with just one or two strokes.

REVIEW QUESTIONS

1. Describe how to mix the soil with water.

2. Describe how to obtain the moisture content sample.

3. What does the liquid limit represent?

4. How is the liquid limit used with the plastic limit?

5. Describe how to adjust the liquid limit apparatus.

PERFORMANCE EXAM CHECKLIST

DETERMINING THE LIQUID LIMIT OF SOILS
FOP FOR AASHTO T 89

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

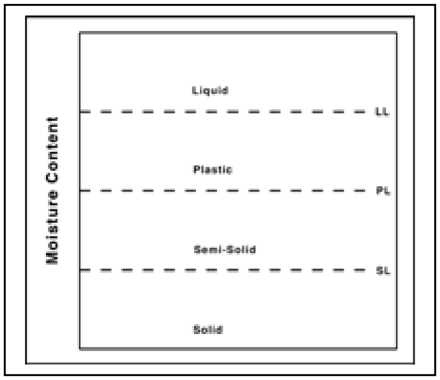
Procedure Element	Trial 1	Trial 2
1. Describe the inspection for wear of the liquid limit device:	_____	_____
a. Wear at contact between cup and base ½" or less?	_____	_____
b. Edge of cup no less than ½ original thickness?	_____	_____
2. Describe how the height of the cup drop is adjusted:	_____	_____
a. Checked before each use?	_____	_____
b. Turn crank while holding gauge in position under cup?	_____	_____
c. Check for ringing or clicking without rising of cup?	_____	_____
d. Cup does not rock?	_____	_____
3. Describe initial sample preparation:	_____	_____
a. Material separated on appropriate sieves?	_____	_____
b. Soil sufficiently pulverized for separation of grains?	_____	_____
c. Material passing the # 40 recombined and mixed?	_____	_____
4. Describe the preparation of the liquid limit sample for Method A:	_____	_____
a. Sample mass approximately 100 g. of minus #40?	_____	_____
b. Mixed in dish with 15 to 20ml of distilled or demineralized water?	_____	_____
c. Mix by stirring, chopping, kneading with spatula until stiff consistency?	_____	_____
d. No dry soil added to lower moisture content?	_____	_____
5. Material placed in cup, centered, 10 mm thick?	_____	_____
6. Soil divided by using up to 6 strokes, preventing tearing or slipping of soil pat?	_____	_____
7. Cup lifted and dropped at a rate of 2 per second?	_____	_____
8. Pat halves come together over length of ½"?	_____	_____
9. Moisture container tare mass determined?	_____	_____
10. Moisture sample properly taken and wet mass determined?	_____	_____
11. Moisture content determined by AASHTO T 265?	_____	_____

12. Multiple tries conducted to achieve sample in shock ranges of 25-35, 20-30, and 15-25? _____ _____
13. Flow curve plotted with shocks on logarithmic scale and the moisture on arithmetic scale? _____ _____
14. Liquid Limit correctly calculated and rounded to nearest whole number? _____ _____
15. Reported on standard agency form? _____ _____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

Signature of Examiner ___________________________________

DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS FOP FOR AASHTO T 90



Material phase and moisture content

01 ## Significance

Fine-grained soils, particularly clays, exhibit
02 different properties at different moisture contents.
At very low moisture contents, the material acts like
a solid. As the moisture content rises, the material
moves from solid to semi-solid to plastic to liquid
03 form.

The moisture content at the boundary between
semi-solid and plastic states is known as the plastic
limit (PL). The moisture content between the
plastic and liquid states is known as the liquid limit
04 (LL). The difference between the plastic and liquid
limits is called the plasticity index (PI), and
indicates the size of the range over which the
material acts as a plastic – capable of being
deformed under stress, but maintaining its form
when unstressed.

Fine-grained soils also exhibit shrinking and swelling as the moisture content changes. As water content increases from dry to wet, no change in volume occurs below a certain moisture content, known as the shrinkage limit (SL). Above the SL, volume increases as moisture content increases.

For these reasons, knowledge of the LL, PL, and PI, and sometimes the SL, are important to quality assurance in roadway construction.

Scope

This procedure covers the determination of the plastic limit and plasticity index of soil in accordance with AASHTO T 90. It is used in conjunction with the FOP for AASHTO T 89, Determining the Liquid Limit of Soils. The three values are used for soil classification and other purposes. This FOP will cover the hand rolling method only. If the plastic limit device method is approved by the agency, see the FOP for AASHTO T 90 for that procedure.

Apparatus

- Dish: preferably unglazed porcelain or similar mixing dish, of approximately 4.5 inch diameter.
- Spatula: having a blade 3 to 4 in. long and about 3/4 in. wide.
- Rolling Surface: a ground glass plate or piece of smooth, unglazed paper.
- Containers: corrosion resistant, suitable for repeated heating and cooling, having close fitting lids to prevent the loss of moisture. One container is needed for each moisture content determination.
- Balance: conforming to AASHTO M 231, class G1, sensitive to 0.01 g with a 1200 g capacity.
- Oven: thermostatically controlled, capable of maintaining temperatures of 230 ±9°F.

Sample

The plastic limit procedure is often run in
05 conjunction with the liquid limit procedure. If this
is the case, the plastic limit sample should be
obtained from the soil prepared for the liquid limit
test at any point in the process at which the soil is
plastic enough to be easily shaped into a ball
without sticking to the fingers excessively when
squeezed. Obtain approximately 8 g of soil to run
the plastic limit test.

If the plastic limit only is to be determined, the sample must be prepared per AASHTO T 87 or T 146. Obtain about 20 g of material passing the No. 40 sieve. Mix the soil with distilled or demineralized water until the mass becomes plastic enough to be easily shaped into a ball. Obtain approximately 8 g of soil to run the plastic limit test.

Note 1: Tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water.

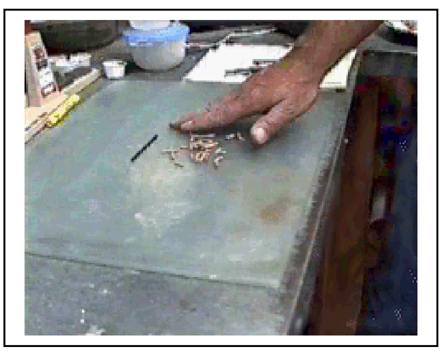
06

07

Rolling the thread

Procedure (Hand Rolling Method)

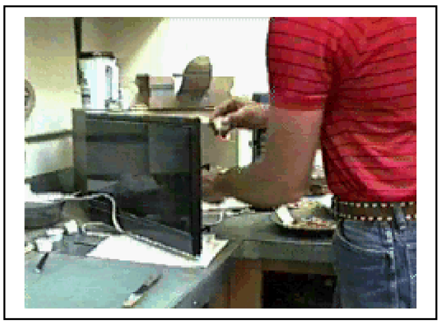
1. From the sample pull a 1.5 to 2 g mass.
2. Squeeze and form the test sample into an ellipsoidal-shape mass.
3. Roll this mass between the fingers or palm and the rolling surface with just sufficient pressure to roll the mass into a thread of uniform diameter along its length. Roll out between 80 and 90 strokes per minute, counting a stroke as one back and forth motion. The sample must be rolled into the 1/8 in. thread in no longer than 2 minutes.
4. Break the thread into six or eight pieces when the diameter of the thread reaches 1/8 in.
5. Squeeze the pieces together between the thumbs and fingers of both hands into an ellipsoidal-shape mass and reroll.
6. Continue this process of alternately rolling to a thread of 1/8 in. diameter, cutting into pieces, gathering together, kneading and rerolling until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread.



Breaking the thread

08

Note 2: Crumbling may occur when the thread has a diameter greater than 1/8 in. This shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread of 1/8 in. diameter. The crumbling will manifest itself differently with various types of soil. Some soils fall apart in many pieces; others form an outside tubular layer that splits at both ends; splitting progresses toward the middle, and the thread falls apart in small platy particles. Heavy clay requires much pressure to deform the thread, particularly as it approaches the plastic limit, and the thread breaks into a series of barrel-shaped segments each 1/4 to 3/8 in. long. At no time shall the tester attempt to produce failure at exactly 1/8 in. diameter. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal-shaped mass nearer to the required 1/8 in. final diameter.



Drying sample

7. Gather the portions of the crumbled soil together and place in a suitable, tared container and cover.
8. Repeat steps one through seven until 8 g of sample have been tested and placed in the covered container.
9. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255/T 265 (Soil).

Plastic Limit

The moisture content, as determined in Step 9
09 above, is the Plastic Limit. It is advisable to run
several trials on the same material to ensure a
proper determination of the Plastic Limit of the soil.

Plasticity Index

The Plasticity Index (PI) of the soil is equal to the difference between the Liquid Limit (LL) and the Plastic Limit (PL).

PI = LL – PL

Examples: **#1**

LL = 34 and PL = 17

PI = 34 – 17 = 17

#2

LL = 16 and PL = 10

PI = 16 – 10 = 6

Example Calculation

Container	Container Mass, g	Container and Wet Soil Mass, g	Wet Soil Mass, g	Container and Dry Soil Mass, g	Dry Soil Mass, g
1	14.44	22.65	8.21	21.45	7.01
2	14.18	23.69	9.51	22.81	8.63

Water Mass, g	Moisture Content	Plastic Limit
1.20	17.1	17
0.88	10.2	10

10

Report

Results shall be reported on standard forms approved by the agency. Report the PL and PI to the nearest whole number.

11

Tips!

- Some soils, such as sandy silts, require very light pressure when rolling.
- If the sample flattens rather than rolling into a thread, it may be too wet.

REVIEW QUESTIONS

1. Describe how to obtain the plastic limit sample if done in conjunction with the liquid limit procedure.

2. Describe the process for determining the plastic limit.

3. What does the plastic limit represent?

4. How is the plastic limit used with the liquid limit?

5. What does the plasticity index represent?

6. Approximately how much soil should be prepared to run the plastic limit test?

7. What is the approximate mass of the ellipsoidal sample?

8. What change in the procedure is permissible for feeble plastic soils?

PERFORMANCE EXAM CHECKLIST

DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS FOP FOR AASHTO T 90

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Describe the preparation of the plastic limit sample:	_____	_____
a. Sample may be obtained from preparations for liquid limit test sample?	_____	_____
b. Sample mass approximately 20 g of minus #40?	_____	_____
c. Mix in dish with enough distilled or demineralized water until easily shaped into ball?	_____	_____
d. Approximately 8 g sample obtained?	_____	_____
2. 1.5 to 2.0 mass obtained from ball?	_____	_____
3. Sample squeezed into ellipsoidal mass?	_____	_____
4. Mass rolled into 1/8" thread at rate of 80-90/min?	_____	_____
5. Thread broken into six or eight pieces, recombined, and rolling repeated?	_____	_____
6. Moisture sample obtained when thread just begins to crumble?	_____	_____
7. Tare mass of moisture container determined?	_____	_____
8. Moisture sample properly taken and wet mass determined?	_____	_____
9. Moisture content determined by the FOP for AASHTO T 265?	_____	_____
10. Multiple tries conducted until 8 g of original sample used?	_____	_____
11. Plastic limit correctly calculated and rounded to nearest whole number?	_____	_____
12. Plasticity index determined by subtracting plastic limit from liquid limit?	_____	_____
13. Plasticity index reported to the whole number?	_____	_____
14. Reported on standard agency form?	_____	_____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

____
____
____
____
____

Signature of Examiner ______________________________________

USE OF AKDOT&PF ATM 212, ITD T 74, WSDOT TM 606, OR WFLHD HUMPHRYS CURVES

Background

01 Coarse-grained granular soils are free-draining and have little or no cohesion. These soils are, therefore, not particularly well suited for the moisture-density relations procedures of AASHTO
02 T 99, or AASHTO T 180. Transportation agencies have developed specialized test methods that are hybrids of those moisture-density procedures and methods that employ compaction under load with vibration. Those methods include:

03

- AKDOT&PF's ATM 212
- ITD's T 74
- WSDOT's TM 606
- WFLHD's Humphrys

Description of Procedure

04 In these tests, material is compacted in a mold and in a manner similar to those used in a Proctor test, after which the material is further compacted through a combination of applied loads and vibration. A laboratory maximum dry density is determined, as is the percent of material passing a certain sieve such as the No. 4. A number of determinations are made for different percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the percentage of material passing that sieve. These tests are conducted in the agency's central lab, and the curve developed is a central lab function. Figure 1 is an example of such a curve.

05

Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM 212, T 74, TM 606, and Humphrys depending on the agency.

In the field, the dry density of the granular material will be determined in accordance with the FOP for AASHTO 310. The percent of material passing the specified sieve will be determined for a sample obtained at the site of the density test. The dry

density and percent passing values will then be compared with the curve developed in the lab for that particular granular material to determine
06 conformance with the project specifications.

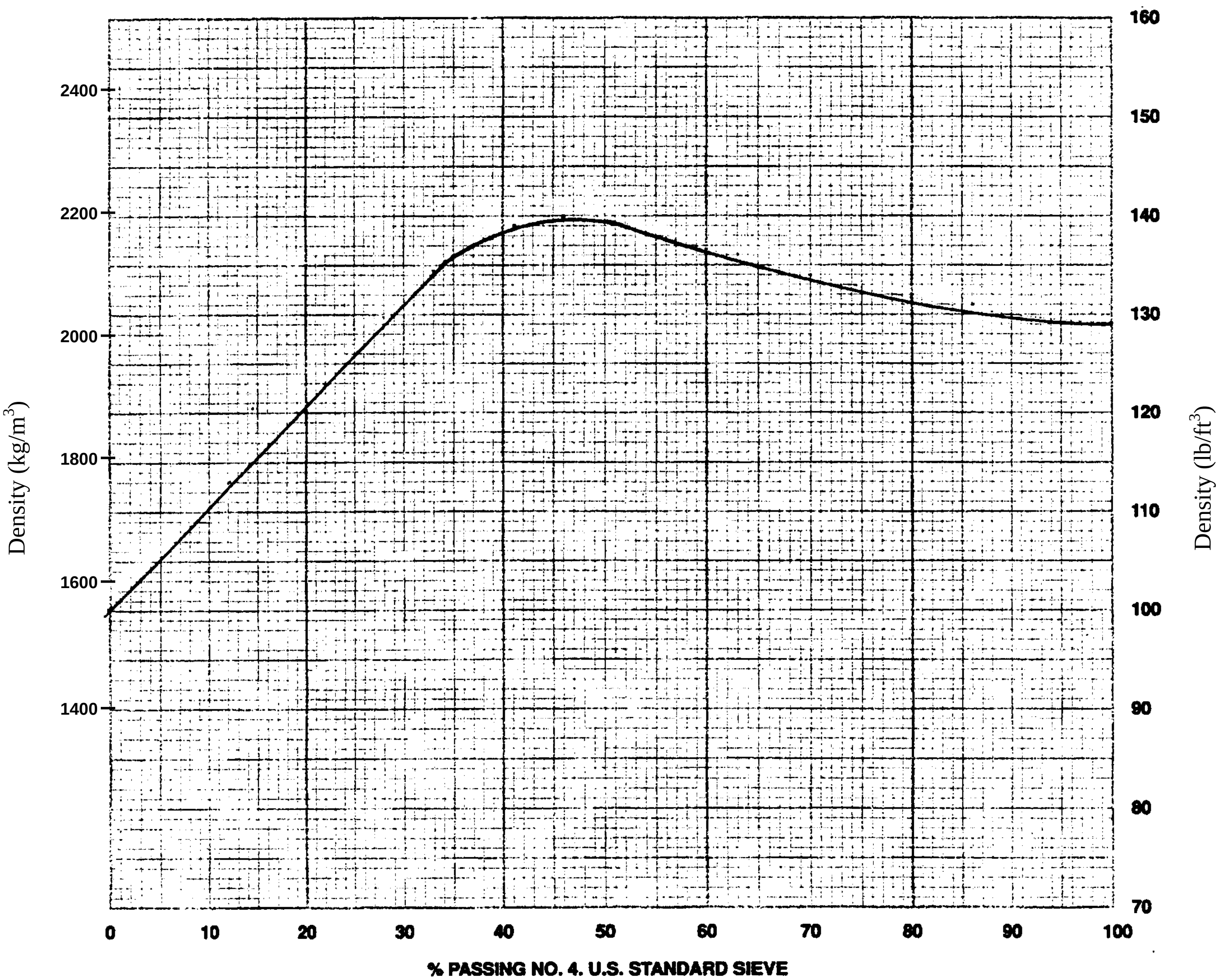


Figure 1. Maximum Density Curve Graph

Example:

A compaction test was taken and a sample was removed from the test site per the FOP for T 310. The sample was graded over a No. 4 sieve. The following results were reported.

Dry Density from T 310 =	137.0 lb/ft^3
Percent passing No.4 sieve =	49% 07
Maximum Density =	139.0 lb/ft^3

Percent Compaction = 99% 08